RESTRICTED

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 911

SOME INVESTIGATIONS OF THE GENERAL INSTABILITY OF STIFFENED METAL CYLINDERS

VII - STIFFENED METAL CYLINDERS SUBJECTED TO COMBINED BENDING AND TORSION

Guggenheim Aeronautical Laboratory
California Institute of Technology

Washington
November 1943

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 911

SOME INVESTIGATIONS OF THE GENERAL INSTABILITY OF STIFFENED METAL CYLINDERS

VII - STIFFENED METAL CYLINDERS SUBJECTED TO COMBINED BENDING AND TORSION

Guggenheim Aeronautical Laboratory
California Institute of Technology

This is the seventh of a series of reports covering an investigation of the general instability problem by the California Institute of Technology. The first five reports of this series cover investigations of the general instability problem under the loading conditions of pure bending and were prepared under the sponsorship of the Civil Aeronautics Administration. This report and succeeding reports of this series cover the work done on other loading conditions under the sponsorship of the National Advisory Committee for Aeronautics.

SUMMARY

This report summarizes the work that has been carried on in the experimental investigation of the problem of the general instability of stiffened metal cylinders subjected to combined bending and torsion at the C.I.T. This part of the investigation included tests on 26 sheet-covered specimens. An interaction curve for the case of combined bending and torsion is presented. The results of tests of 17 specimens subjected to pure torsion are also given.

INTRODUCTION

It is intended to give in this report a summary of the experimental investigation of the general instability

of stiffened metal cylinders subjected to combined bending and torsion. The earlier work at the C.I.T. on the problem of the general instability of stiffened metal cylinders has been reported in references 1, 2, 3, 4, 5, and 6. A total of 26 sheet-covered specimens has been tested to determine the effects of combined loading and bending plus torsion, and an additional 17 specimens have been tested to determine the effects of a pure torsion load. In the present report, the results of tests in combined bending and torsion are discussed and the test data of the pure torsion tests are also included.

TESTS IN COMBINED BENDING AND TORSION

Testing Apparatus

A complete description of the testing machine used in these tests is given in reference 2. This machine (fig. 1) is adapted to the application of either pure bending or pure torsion or any combination of bending and torsion.

For the present tests, it was desired to apply a uniform bending and uniform torsion simultaneously. The ratio of the two loads was different for different specimens. In order to apply uniform bending, the moment arms were connected by an extra flexible aircraft cable attached at one end to a loading screw which in tern was attached to a loading dynamometer. For the application of uniform torsion, one of the torsion arms was fixed while the load was applied to the arm by means of a loading screw.

Testing Procedure

The desired loading required a simultaneous application of bending and torsion, the ratio of the two loads being fixed by any given test. During the application of any load increment the ratio of bending to torsion was closely maintained. This result was accomplished by preparing a loading schedule for each test and, by calling out the bending load as it was applied, the two operators could maintain the proper loading ratio.

The axial strain in the longitudinal stiffeners was measured by means of resistance strain gages of 16-inch

length. These strain gages were mounted on the neutral axis of the stiffeners and were also mounted in pairs — one on each side of the stiffener — in order that the mean reading would be unaffected by bending. These strain measurements were taken at the center of the specimen, that is, the center of the strain gage was placed at the center of the cylinder.

Inasmuch as the specimen was subjected to uniform loadings, both bending and torsion, the unit axial strain for any loading increment can also be obtained by measuring the mean strain over the entire specimen. The measurements were obtained by measuring the over-all deformation of the specimen by means of a dial gage mounted on a rigid rod. A sharp pointed fitting was attached to one end of the rod and another to the dial plunger. Inserting these pointed fittings into punch marks on the mounting ring near the surface of the specimen allowed consistent measurements of the over-all deformation to be obtained for each load increment.

In order to investigate the complete range of the ratios of bending to torsion, a specimen was first tested under pure torsion and the ratio of bending to shear was then increased in subsequent tests. The ultimate strength in pure bending was obtained from the experimental curve of the pure bending tests given in reference 5.

Results of Combined Loading

For the investigation of combined loadings only three types of cylinders were tested, namely, two series that had a frame spacing of 4 inches and a longitudinal stiffness spacing of 5.06 and 2.53 inches in which the frames were F_5 and the longitudinals S_2; and a series that had a frame spacing and longitudinal stiffness spacing of 4 and 2.53 inches, respectively, in which the frames were F_5 and the longitudinals S_1. The frame and longitudinal cross sections are shown in figure 2 and the positions of the dial strain-gages is indicated in figure 3. It was felt that three types of cylinders would be sufficient to determine the dependence of the failing load on the ratio of the combined loading. The experimental data for all test specimens are given in table I.

The compressive unit strain for the longitudinal farthest from the neutral axis as a function of the applied

bending moment is shown for the various tests in figures 4 to 28. The resulting unit strain as obtained from the resistance strain gages and the unit strain obtained from the dial-gage measurements are indicated in each figure. These results indicate that, in general, fair agreement is obtained between these two types of measurements. In only a few tests is the agreement exact.

The variation of the stiffener strain around the circumference as a function of the applied load is also shown for a number of specimens (figs. 4, 5, 7, 8, 11, 12, 15, and 17). The circumferential position of the various gages is indicated in figure 3. The results of these tests have been cross-plotted in figures 29 to 35 to indicate the distribution of normal stiffener strain for increasing loads as a function of the distance from the horizontal axis. The results of figure 29 indicate that the torsional load results in a secondary compressive strain of nearly constant magnitude.

Under a condition of pure bending, a shift in the neutral axes towardsthe tension side occurs when compression buckling of the sheet takes place. The secondary compressive strain causes a farther shift. In particular, when the ratio of bending to torsion is small, the distribution of strain will be compressive in nature over the entire specimen (fig. 30). This secondary compression strain is probably entirely due to the diagonal tension field that develops in the sheet covering.

The ultimate stress at failure has been presented in the form of the well-known interaction curves; that is, σ/σ_0 is plotted as a function of τ/τ_0 where σ is the normal compression stress at failure for combined loading and σ_0 is the same stress at failure for pure bending, and similarly, τ and τ_0 are the shearing stresses at failure for combined loading and pure torsion, respectively. The shearing stresses are computed by the equation

$$\tau = \frac{M}{2\,At}$$

where

M applied torque, pounds

A area enclosed by the sheet covering, square inches

t sheet thickness, inches

Two sets of data are shown. The first set (fig. 36) corresponds to stresses as measured by the resistance strain gages and the second set (fig. 37) to the stresses as obtained from the dial-gage measurements. In either case a considerable amount of scatter is evident. The interaction equations of the form

$$\left(\frac{\sigma}{\sigma_0}\right)^2 + \left(\frac{\tau}{\tau_0}\right)^2 = 1 \tag{1}$$

and

$$\frac{\sigma}{\sigma_0} + \left(\frac{\tau}{\tau_0}\right)^2 = 1 \tag{2}$$

are compared with the experimental results. Figure 36 indicates that for the resistance strain-gage measurements about two-thirds of the test values lie fairly close to the curve of equation (2); whereas the majority of the dial-gage measurements scatter about the curve of equation (1). It should be noted that for the pure bending specimen (specimen 159), the strain at failure measured by the resistance strain gages is considerably lower than the strain of the preceding combined loading specimens. For this reason a failing strain of 0.0019 was used to determine σ_0. This value was obtained from the pure bending parameter and agrees fairly well with the dial gage reading.

PURE TORSION

So far, the investigation has covered the ultimate strength of reinforced cylinders under purebending and the influence of combined loadings; that is, combined bending and transverse shear and combined bending and torsion. In order to use this data for design purposes, it is still necessary to determine the ultimate strength of reinforced cylinders when loaded in pure shear, that is, a pure torsion loading. Tests of this nature are

necessary in order to ascertain the value of τ/τ_0 for any given design problem.

An attempt will be made to determine a suitable shear parameter in a manner similar to that used to determine the pure bending parameter. This method requires a systematic investigation of the variables dealing with the geometry of the structure and the variables that involve the sectional properties of the stiffening elements as well as the sheet covering. Seventeen pure torsion tests have been completed and the specimens and test data for these tests are given in table II. Additional testing is necessary before an analysis of the data can be attempted. Photographs (figs. 38 to 44) show a number of specimens after failure. For purposes of comparison, photographs are included of specimens in combined bending and torsion.

CONCLUSIONS

(1) Inasmuch as the specimens were built and tested with the usual care of experimental work, it is felt that similar structures built under production conditions would be subject to at least the same variations of ultimate strength as the specimens that were tested. The experimental results of the tests in combined bending and torsion are therefore considered satisfactory in that they indicate the lower strength limit which can be expected in practice. It is seen from figures 2 and 3 that equation (2) described this lower limit fairly well.

(2) Additional testing is necessary before an analysis of the data on pure torsion can be attempted.

Guggenheim Aeronautical Laboratory,
California Institute of Technology,
Pasadena, Calif., Feb. 18, 1943.

REFERENCES

1. Guggenheim Aeronautical Laboratory, California Institute of Technology. Some Investigations of the General Instability of Stiffened Metal Cylinders. I - Review of Theory and Bibliography. T.N. No. 905, NACA, 1943.

2. Guggenheim Aeronautical Laboratory, California Institute of Technology. Some Investigations of the General Instability of Stiffened Metal Cylinders. II - Preliminary Tests of Wire-Braced Specimens and Theoretical Studies. T.N. No. 906, NACA, 1943.

3. Guggenheim Aeronautical Laboratory, California Institute of Technology. Some Investigations of the General Instability of Stiffened Metal Cylinders. III - Continuation of Tests of Wire-Braced Specimens and Preliminary Tests of Sheet-Covered Specimens. T.N. No. 907, NACA, 1943.

4. Guggenheim Aeronautical Laboratory, California Institute of Technology. Some Investigations of the General Instability of Stiffened Metal Cylinders. IV - Continuation of Tests of Sheet-Covered Specimens and Studies of the Buckling Phenomena of Unstiffened Circular Cylinders. T.N. No. 908, NACA, 1943.

5. Guggenheim Aeronautical Laboratory, California Institute of Technology. Some Investigations of the General Instability of Stiffened Metal Cylinders. V - Stiffened Metal Cylinders Subjected to Pure Bending. T.N. No. 909, NACA, 1943.

6. Guggenheim Aeronautical Laboratory, California Institute of Technology. Some Investigations of the General Instability of Stiffened Metal Cylinders. VI - Stiffened Metal Cylinders Subjected to Combined Bending and Transverse Shear. T.N. No. 910, NACA, 1943.

TABLE I

COMBINED BENDING AND TORSION

Specimen	Sheet thickness (in.)	Radius (in.)	Frame	Stiffener	Frame spacing (in.)	Longitudinal spacing (in.)	Torsion bending	Ultimate bending moment (in.-lb)	Ultimate torsional moment (in.-lb)	Compressive strain at failure (in./in.)	Shear stress at failure (lb/sq in.)
149	.010	16	F_5	S_2	4	5.06	Torsion	0	1070×10^2	5.60×10^{-4}	6650
150							5/1	216×10^2	1080	7.64	6710
151							3/1	287	860	7.12	5340
152							2/1	472	945	10.70	5870
153							1/1	770	770	13.5	4780
154							1/1.5	900	600	14.6	3730
155							1/2	1000	500	18.6	3110
156							1/2.5	1175	470	18.05	2920
157							1/3	1150	385	16.2	2390
158							1/3.5	1210	355	16.7	2200
159							Bending	1400	0	16.0	0
160							1/1.5	875	583	14.4	3620
161						5.06	1/5	1200	240	16.2	1490
162						2.53	Torsion	0	1300	2.12	8080
163							1/1	820	820	7.00	5100
164							2/1	575	1150	5.27	7150
165							1/2	1390	695	10.95	4320
166							1/3	1900	633	14.00	3930
167							1/5	2540	508	17.6	3160
168							1/2	1600	800	12.5	4970
169							1/1	1050	1050	9.4	6520
170				S_2			2/1	550	1100	5.25	6840
171				S_1			Torsion	0	1185	1.85	7360
172							1/1	900	900	9.75	5590
173							1/2	1280	645	14.10	4010
174	.010	16	F_5	S_1	4	2.53	1/4	1880	460	21.40	2860

TABLE II

PURE TORSION

Specimen	Sheet thickness	Radius (in.)	Frame	Stiffener	Frame spacing (in.)	Stiffener spacing (in.)	Ultimate torsion moment (in.-lb)	Shear stress at failure (lb/sq in.)
175	.010	16	F_5	S_1	8	2.53	800	4975
176	.010				2	2.53	1600	9950
177	.015				16	5.06	500	2070
178	.015				8		750	3100
179	.015				4		1090	4520
180	.015				2		1700	7050
181	.020				16		730	2270
182	.020				8		925	2870
183	.020				4		1350	4200
184	.020				2	5.06	2335	7240
185	.015	10			8	5.25	380	4030
186	.015	10			4	5.25	630	6680
187	.015	10			2	5.25	890	9440
189	.010	16			32	10.12	130	810
190	.010				16	10.12	250	1555
191	.010				8	10.12	410	2550
192	.010	16	F_5	S_1	4	10.12	676	4200

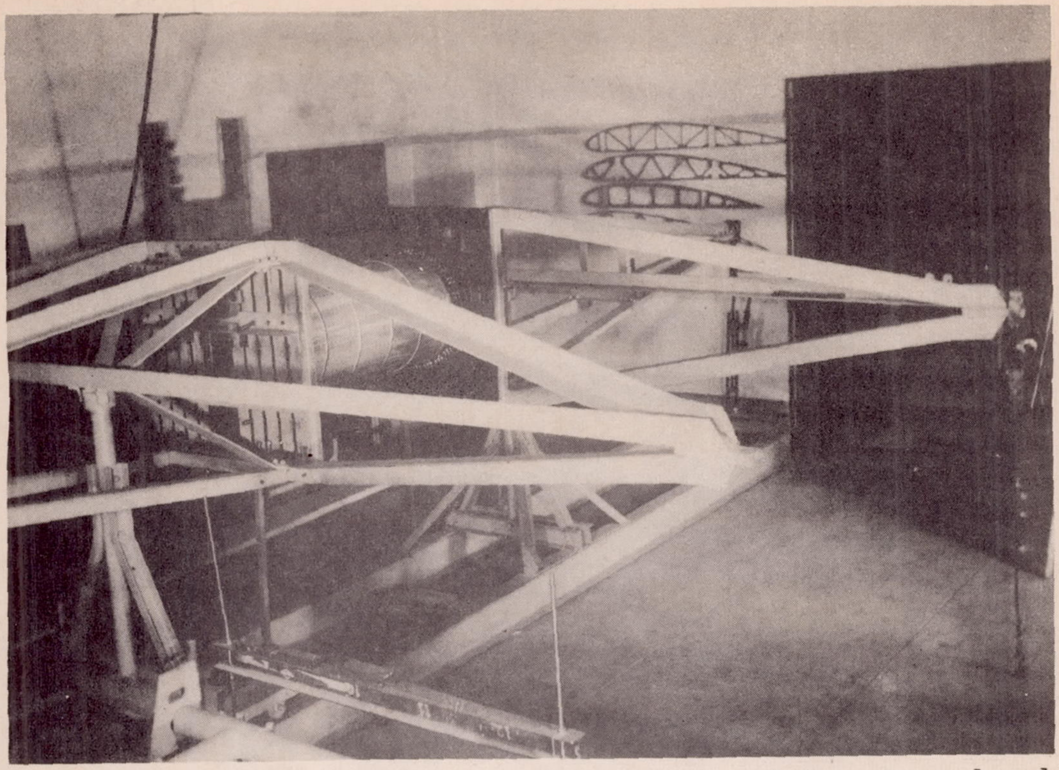


Figure 1.- Testing machine used to apply either pure bending or pure torsion or any combination of bending or torsion.

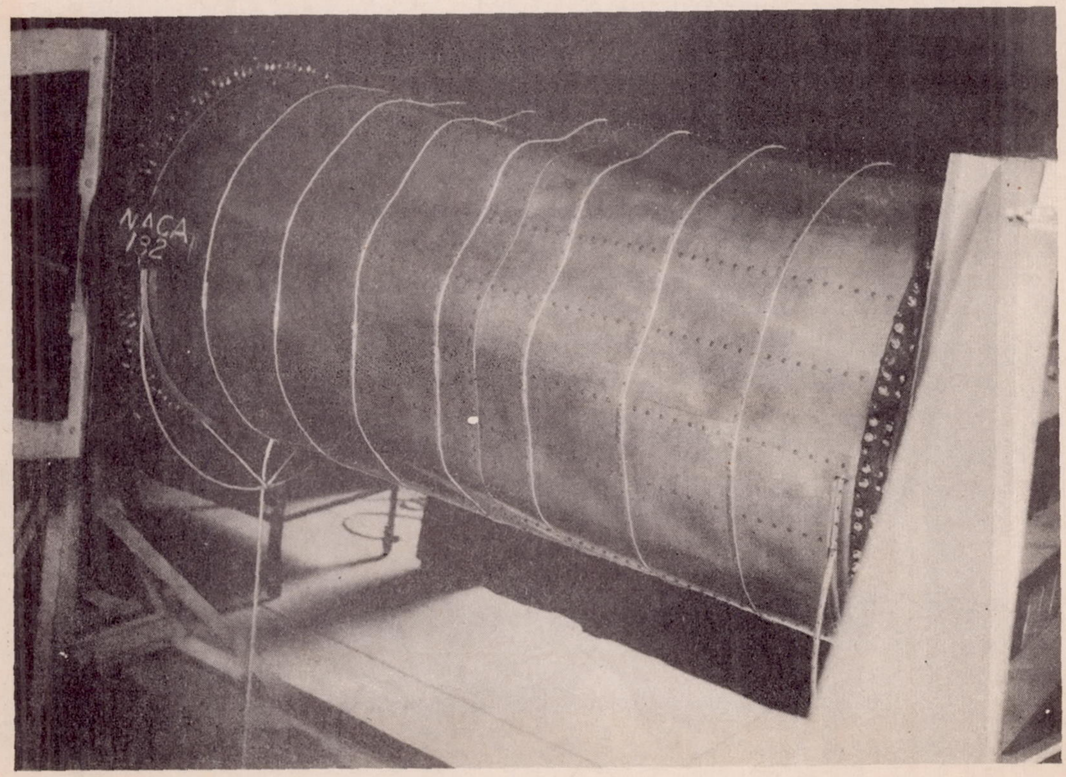


Figure 44.- Pure torsion.

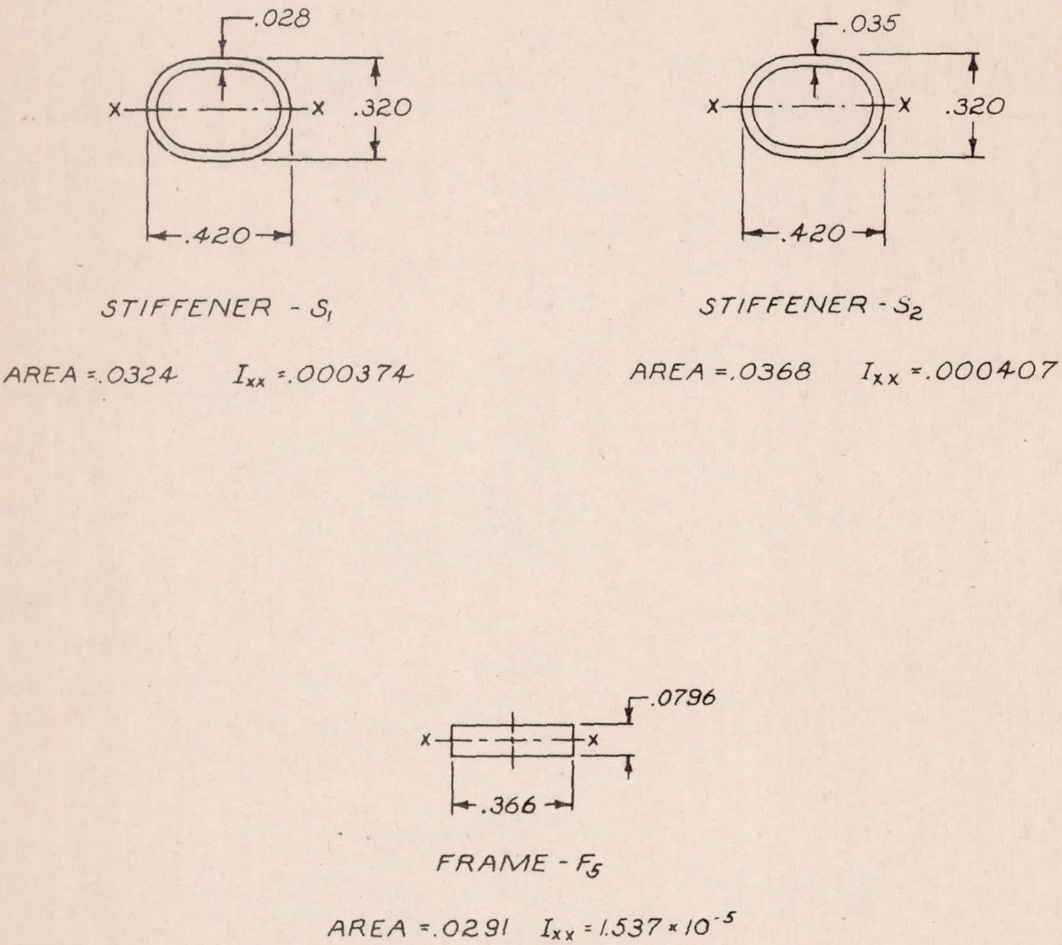


Figure 2.- Frame and longitudinal cross sections used on specimens.

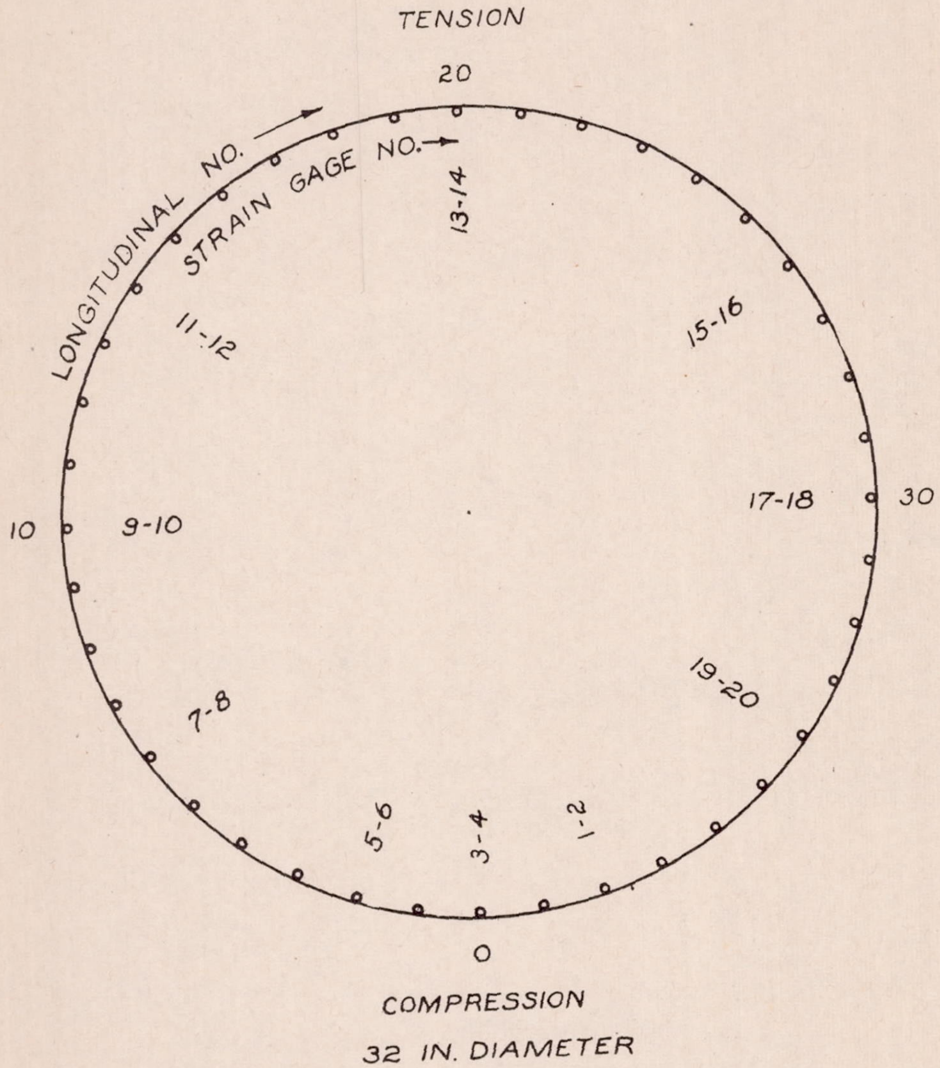
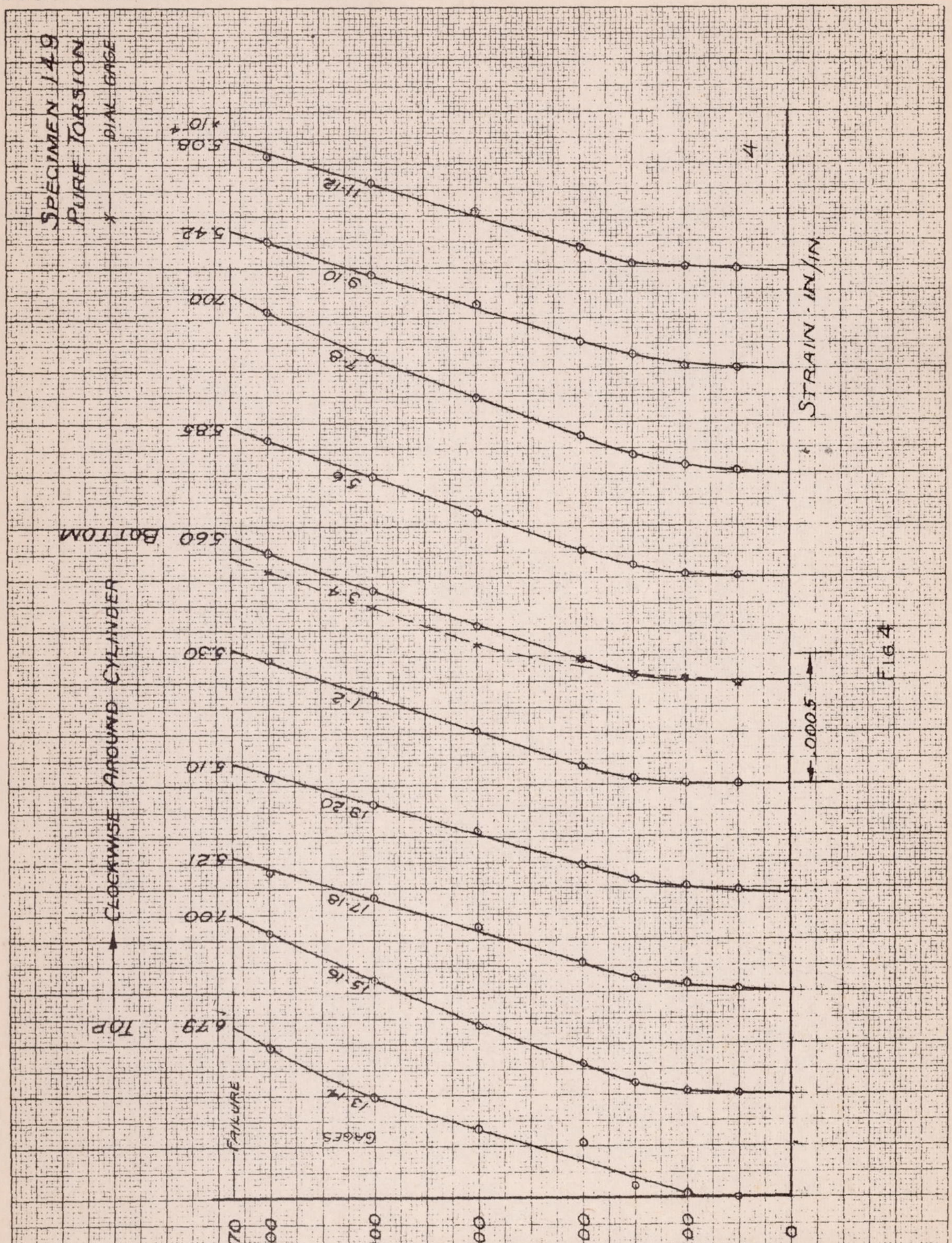
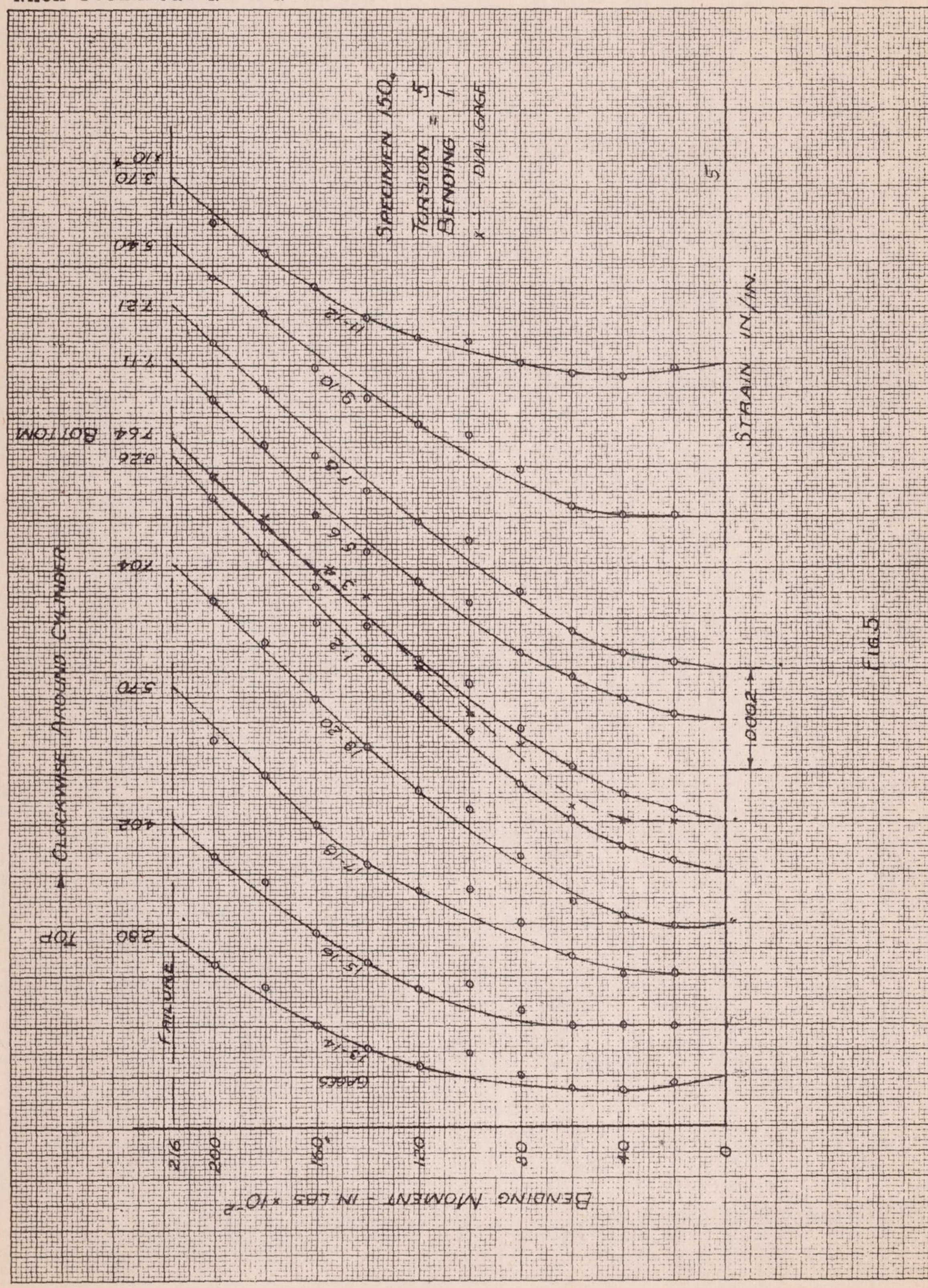


Figure 3.- Cross section of cylinder showing position of the dial strain gages on the circumference.


SPECIMEN 149
PURE TORSION
× DIAL GAGE
STRAIN - IN./IN.
CLOCKWISE AROUND CYLINDER
TOP
BOTTOM
FAILURE
GAGES
.0005
TORSION - IN.LBS × 10^-2
FIG 4


SPECIMEN 150.
TORSION / BENDING = 5 / 1
x — DIAL GAGE
STRAIN IN./IN.
.0002
TOP — CLOCKWISE AROUND CYLINDER
BOTTOM
FAILURE
GAGES
BENDING MOMENT - IN LBS ×10^-2
FIG. 5

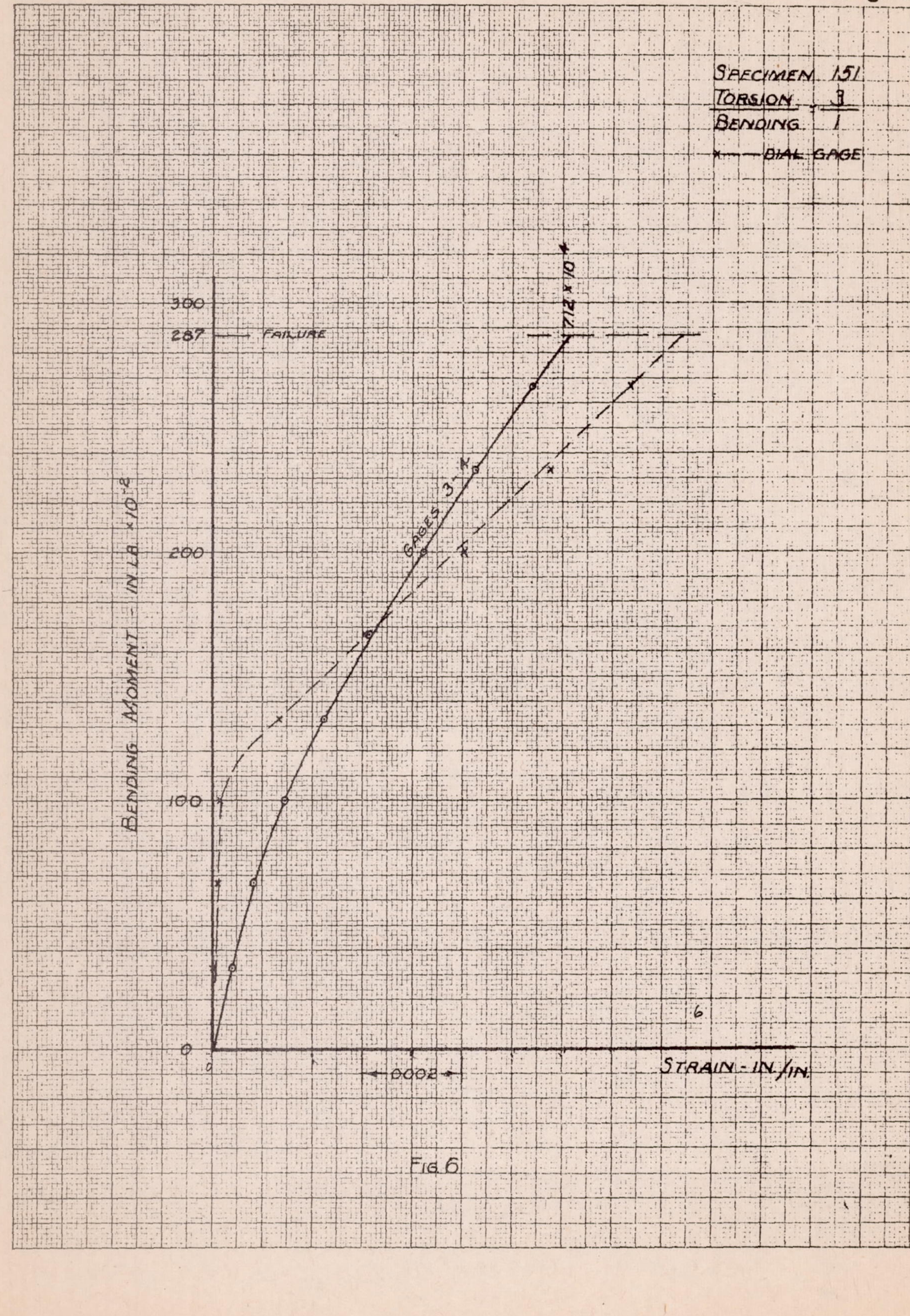

SPECIMEN 151
TORSION 3
BENDING 1
DIAL GAGE
300
287
FAILURE
200
100
0
BENDING MOMENT - IN LB ×10⁻²
GAGES 3-4
712 × 10⁻⁴
.0002
STRAIN - IN./IN.
6

Fig 6

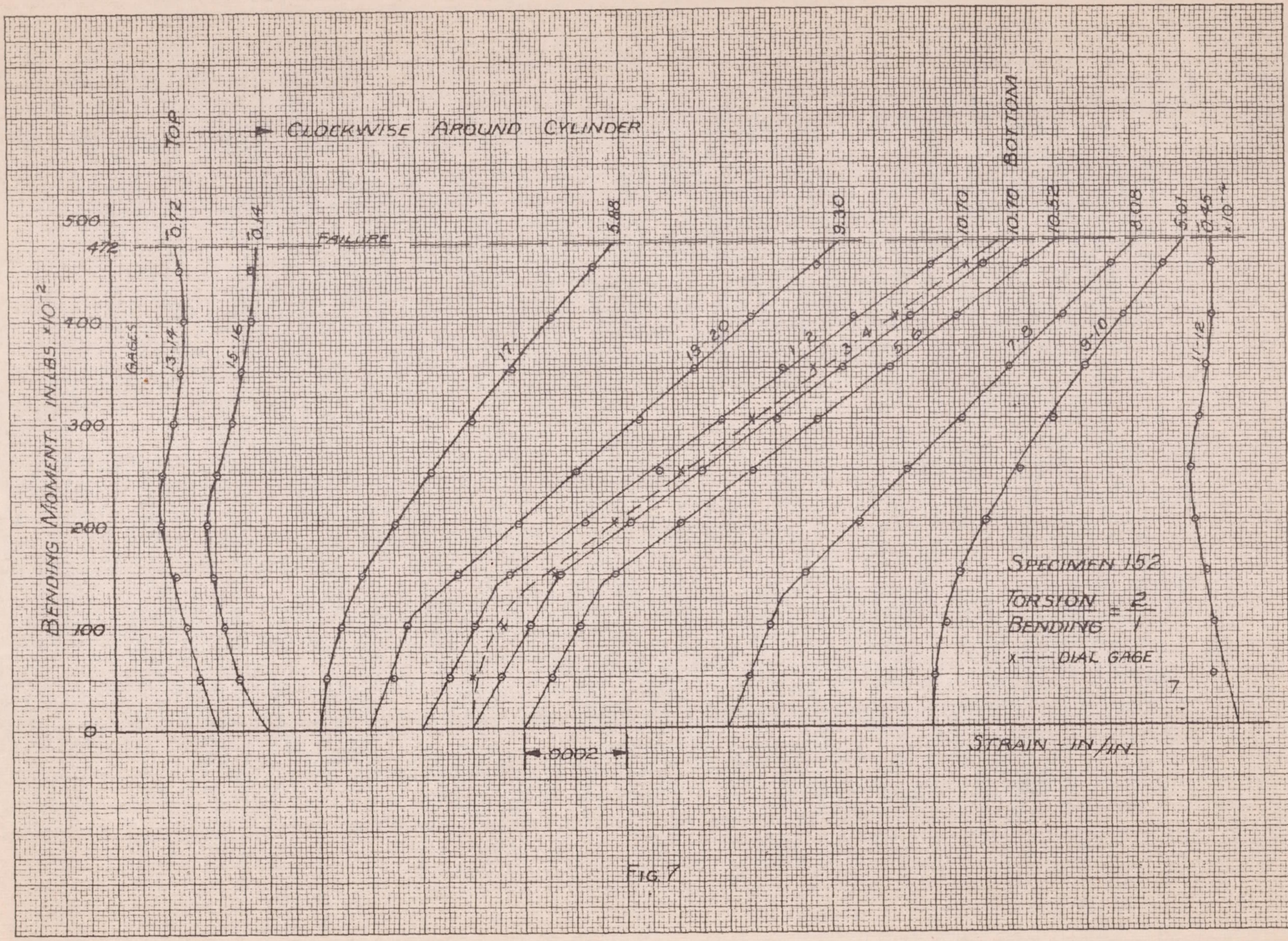
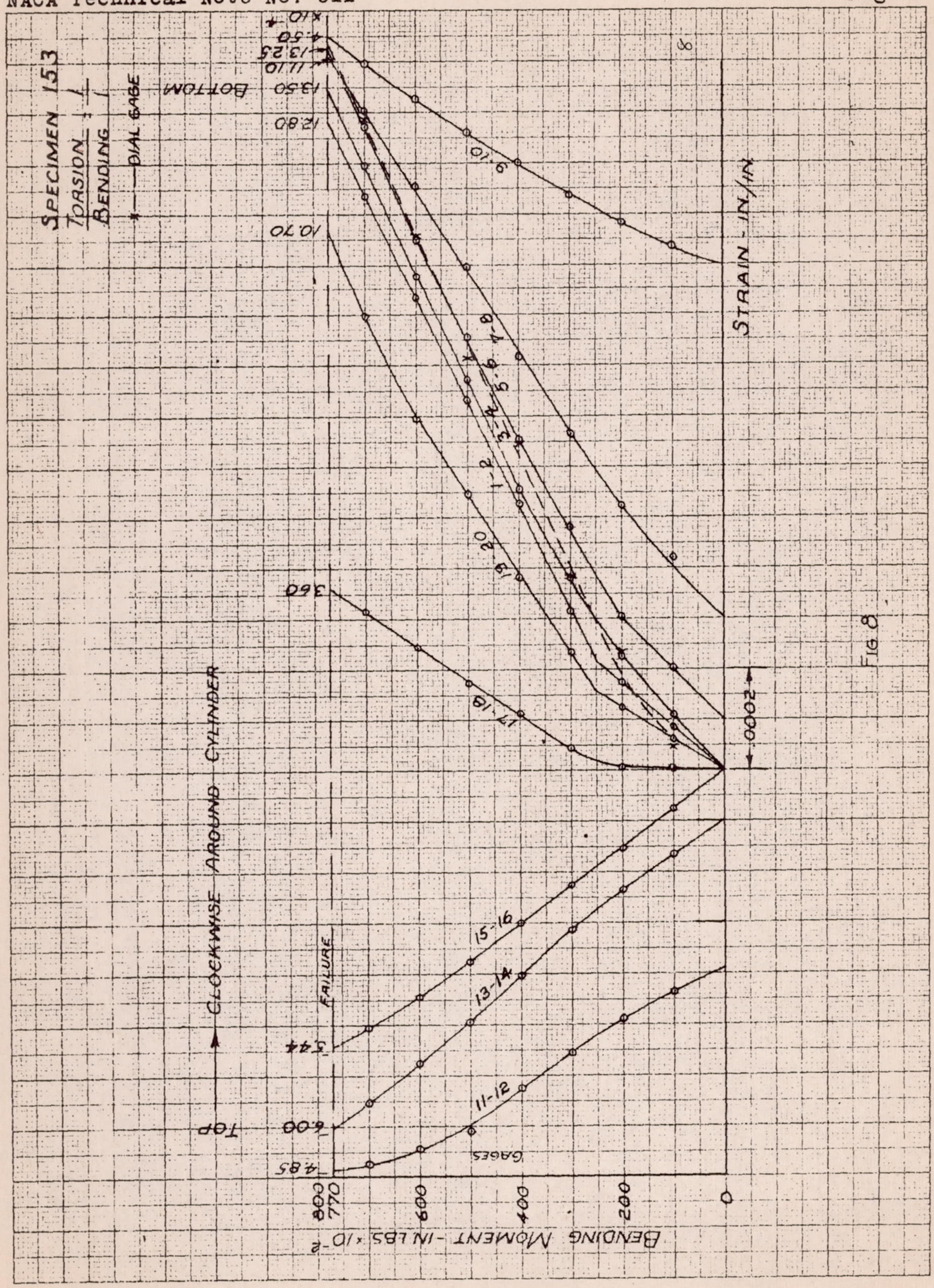

TOP → CLOCKWISE AROUND CYLINDER
BOTTOM
FAILURE
BENDING MOMENT - IN.LBS ×10^2
GAGES
13-14
15-16
17
19-20
1-2
3-4
5-6
7-8
9-10
11-12
0.72
0.14
5.88
9.30
10.70
10.70
10.52
8.08
5.01
0.45
×10^-4
500
472
400
300
200
100
0
.0002
STRAIN - IN./IN.
SPECIMEN 152
TORSION / BENDING = 2 / 1
x—— DIAL GAGE

FIG. 7


SPECIMEN 153
TORSION : 1
BENDING : 1
DIAL GAGE
BOTTOM
TOP
CLOCKWISE AROUND CYLINDER
FAILURE
GAGES
STRAIN - IN/IN
.0002
BENDING MOMENT - IN LBS ×10^-2
800
770
600
400
200
0
4.85
6.00
5.44
3.60
10.70
12.80
13.50
11.10
13.25
4.50
×10^-4
11-12
13-14
15-16
17-18
19-20
1-2
3-4
5-6
7-8
9-10
8
FIG. 8

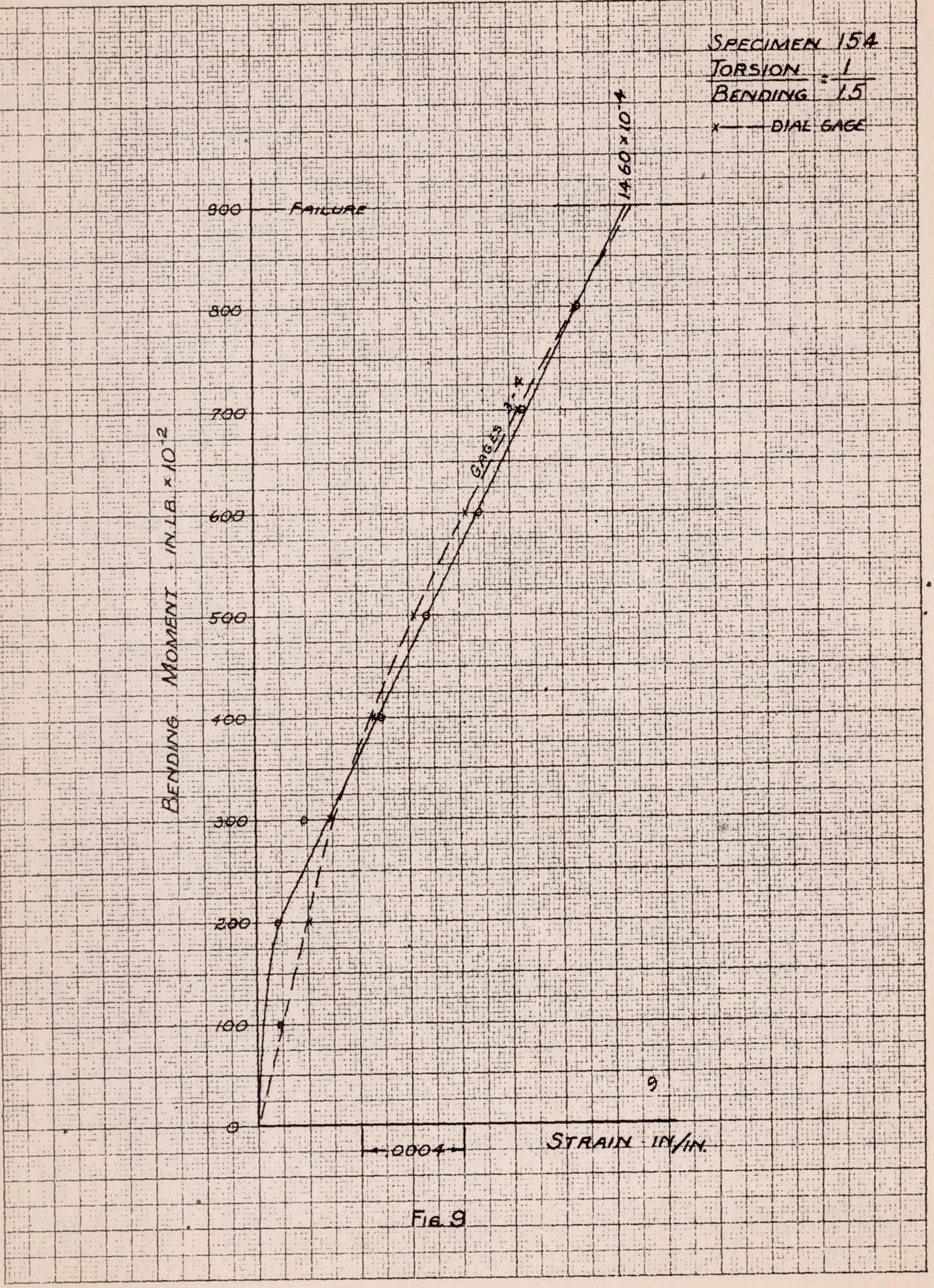

SPECIMEN 154
TORSION / BENDING = 1 / 1.5
x—— DIAL GAGE
14.60 x 10⁻⁴
FAILURE
900
800
700
600
500
400
300
200
100
0
BENDING MOMENT · IN.LB. × 10²
GAGES 3 4
STRAIN IN/IN.
.0004
9

Fig. 9

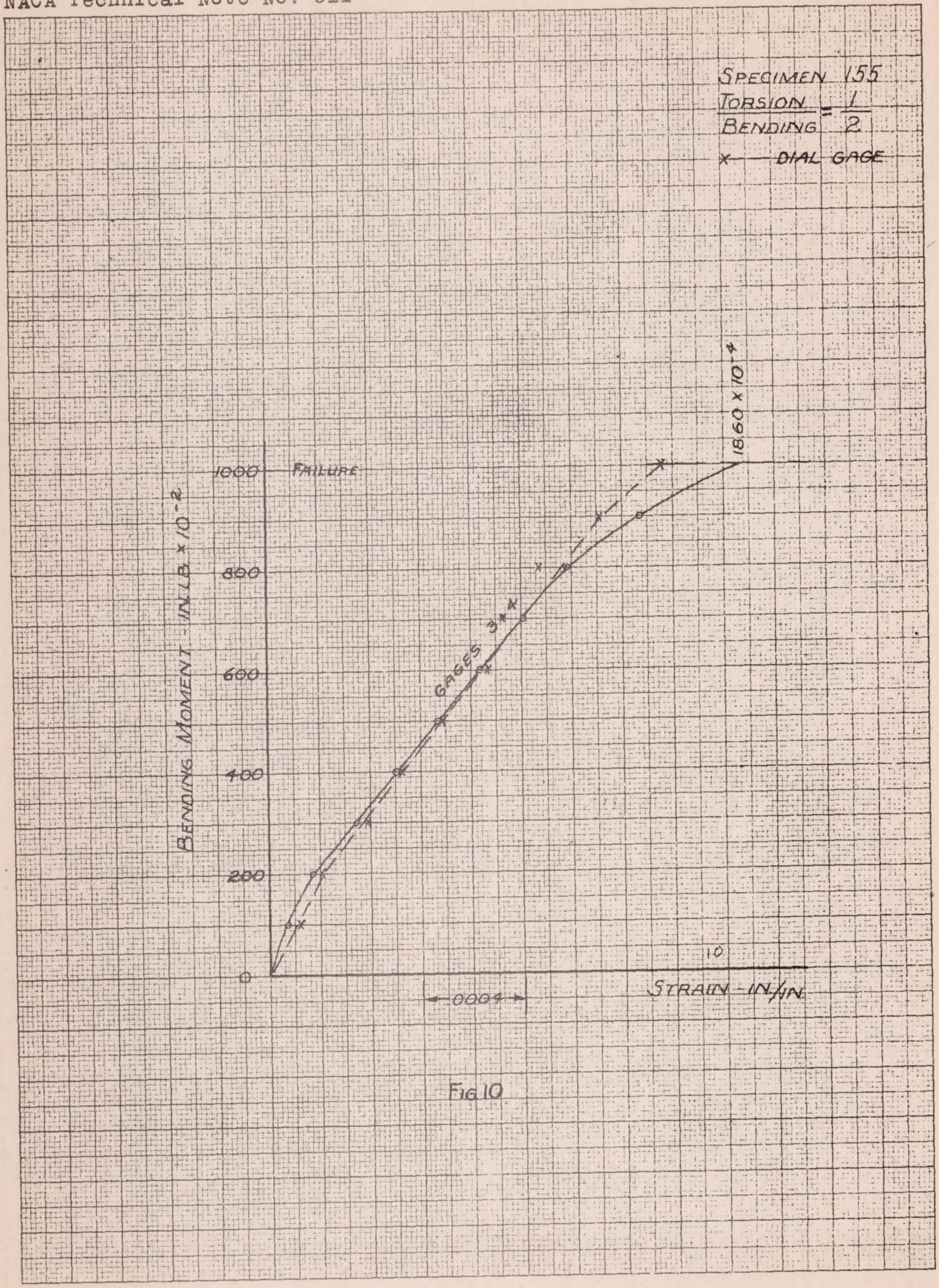
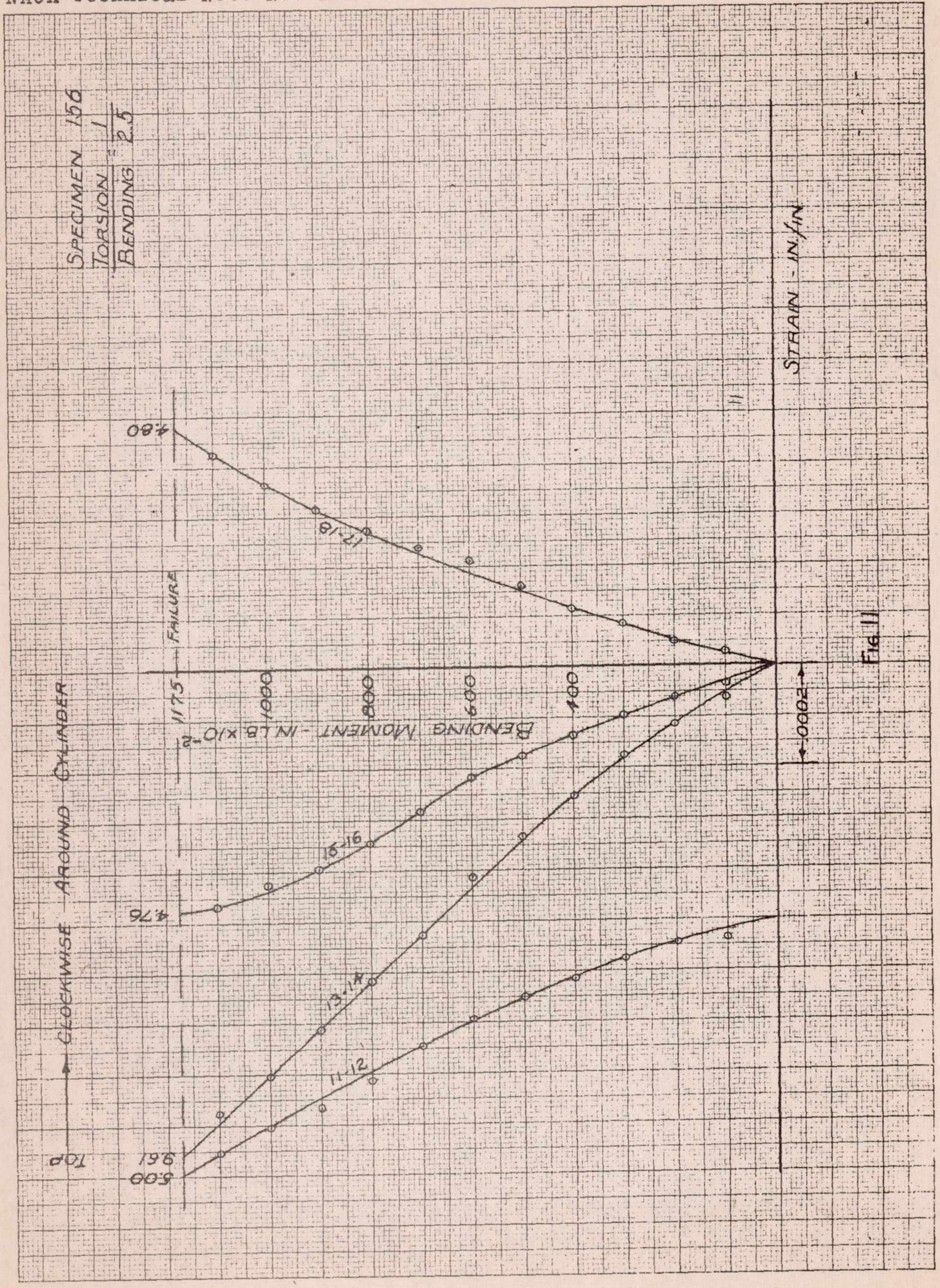
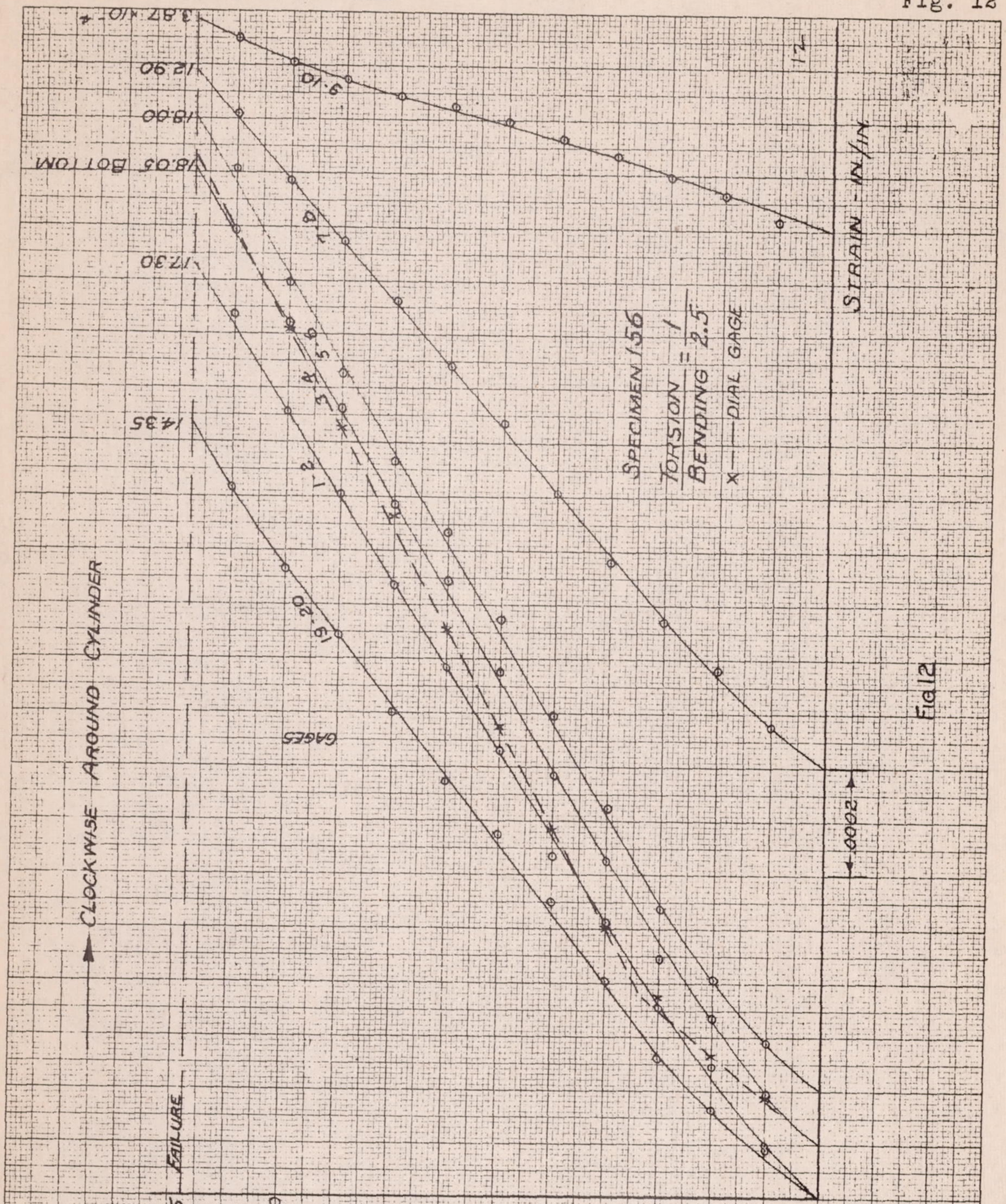
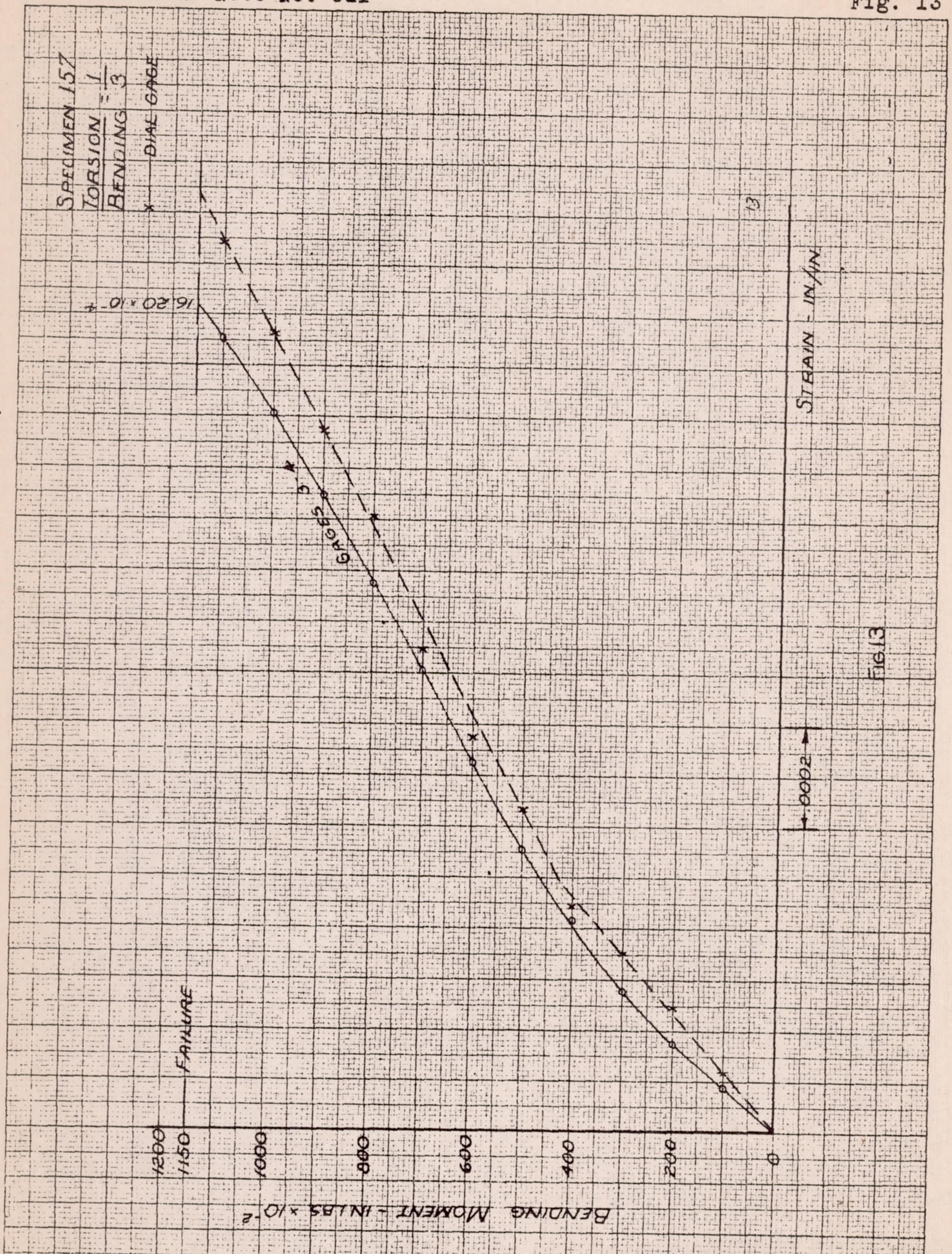

SPECIMEN 155
TORSION / BENDING = 1/2
x — DIAL GAGE
18.60 x 10⁻⁴
1000
FAILURE
800
600
400
200
0
BENDING MOMENT - IN.LB x 10⁻²
GAGES 3 & 4
10
STRAIN - IN/IN.
.0004

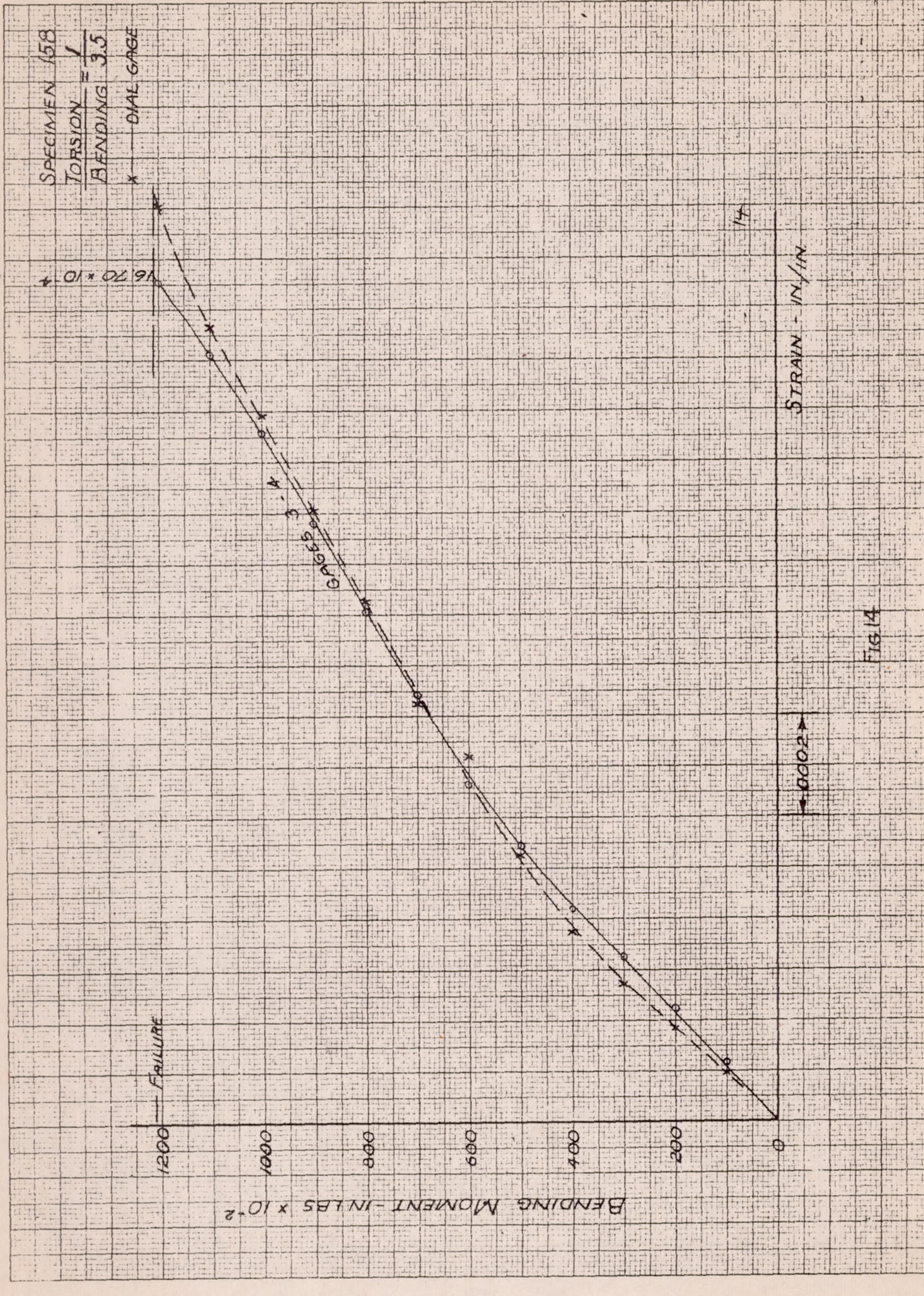
Fig 10


SPECIMEN 156
TORSION / BENDING = 1 / 2.5
CLOCKWISE AROUND CYLINDER
TOP
BENDING MOMENT - IN LB x10^-2
STRAIN - IN/IN
FAILURE
1175
1000
800
600
400
17-18
15-16
13-14
11-12
4.80
4.76
5.00
.0002
FIG. 11

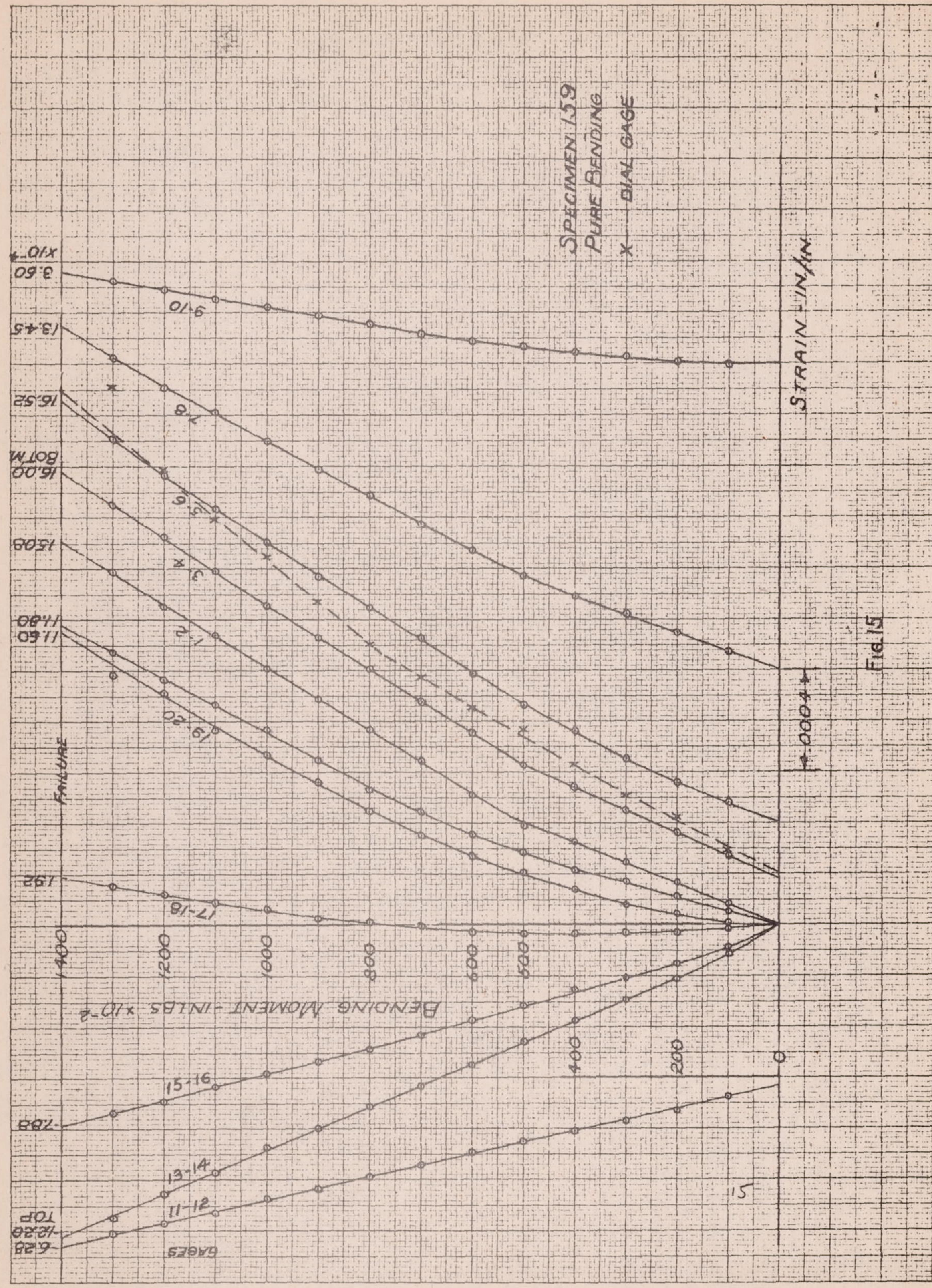

Specimen 156
Torsion / Bending = 1 / 2.5
x — Dial gage
Strain - in/in
.0002
Clockwise around cylinder
Gages
Failure
Bending moment - in lbs ×10⁻²
1175
1000
800
600
400
200
0
3.87 ×10⁻⁴
12.90
18.00
18.05 Bottom
17.30
14.35
9,10
7,8
3,4
5,6
1,2
19,20
Fig 12



SPECIMEN 157
TORSION / BENDING = 1/3
× — DIAL GAGE
16.20 × 10⁻⁴
GAGES 3
STRAIN - IN/IN
.0002
FAILURE
1200
1150
1000
800
600
400
200
0
BENDING MOMENT - IN LBS × 10⁻²
Fig.13



SPECIMEN 158
TORSION / BENDING = 1 / 3.5
× — DIAL GAGE
16.70 × 10^-4
GAGES 3-4
FAILURE
STRAIN - IN./IN.
.0002
BENDING MOMENT - IN LBS × 10^-2
0
200
400
600
800
1000
1200
FIG. 14


SPECIMEN 159
PURE BENDING
X — DIAL GAGE
STRAIN - IN/IN.
BENDING MOMENT - IN LBS x10^-2
FAILURE
GAGES
TOP
BOT'M
9-10
7-8
5-6
3-4
1-2
19-20
17-18
15-16
13-14
11-12
←.0004→
FIG. 15

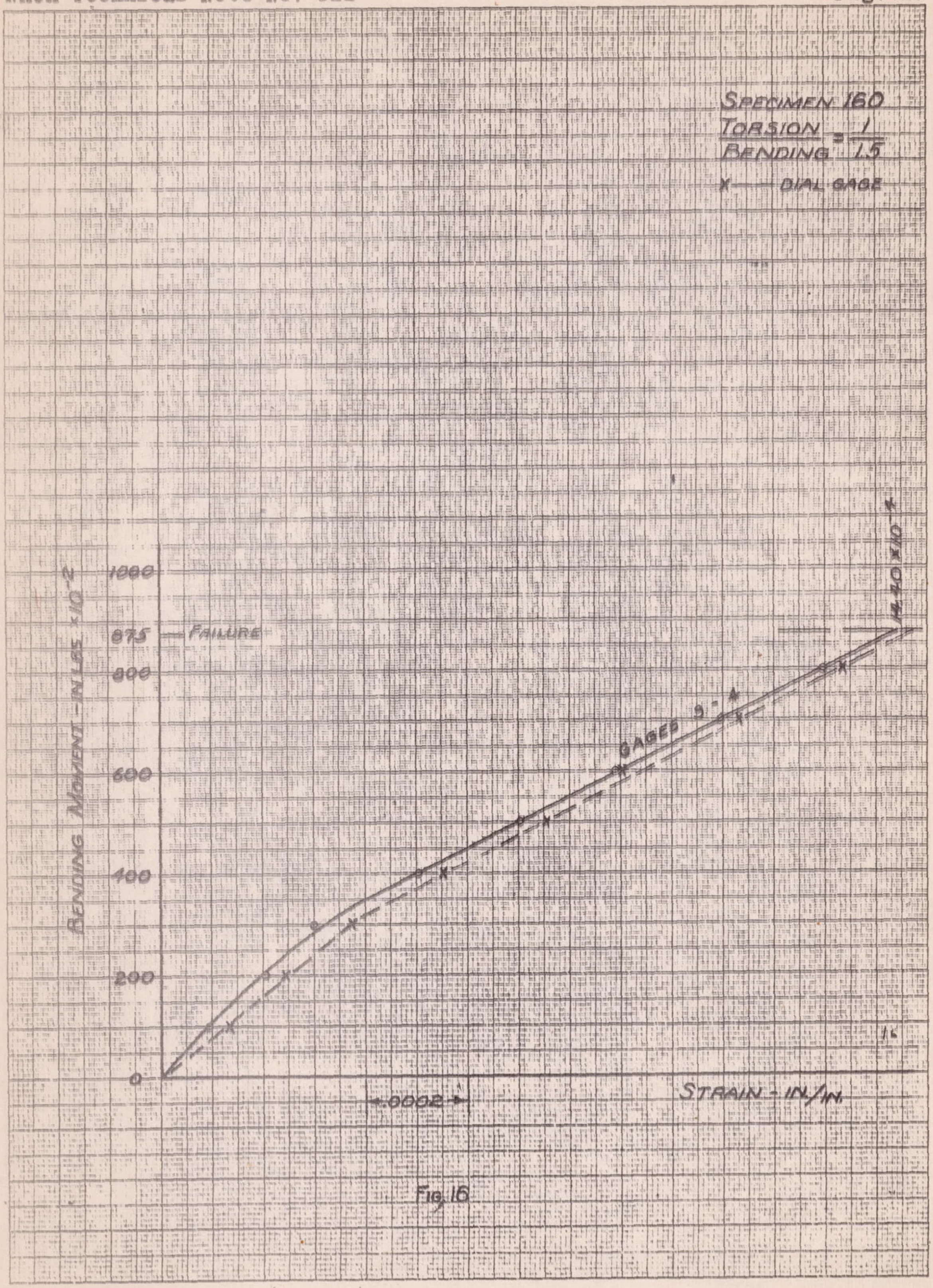

SPECIMEN 160
TORSION / BENDING = 1 / 1.5
X —— DIAL GAGE
BENDING MOMENT - IN LBS ×10⁻²
1000
875 — FAILURE
800
600
400
200
0
GAGES 3 - 4
14.40×10⁻⁴
STRAIN - IN/IN.
←.0002→

Fig. 16

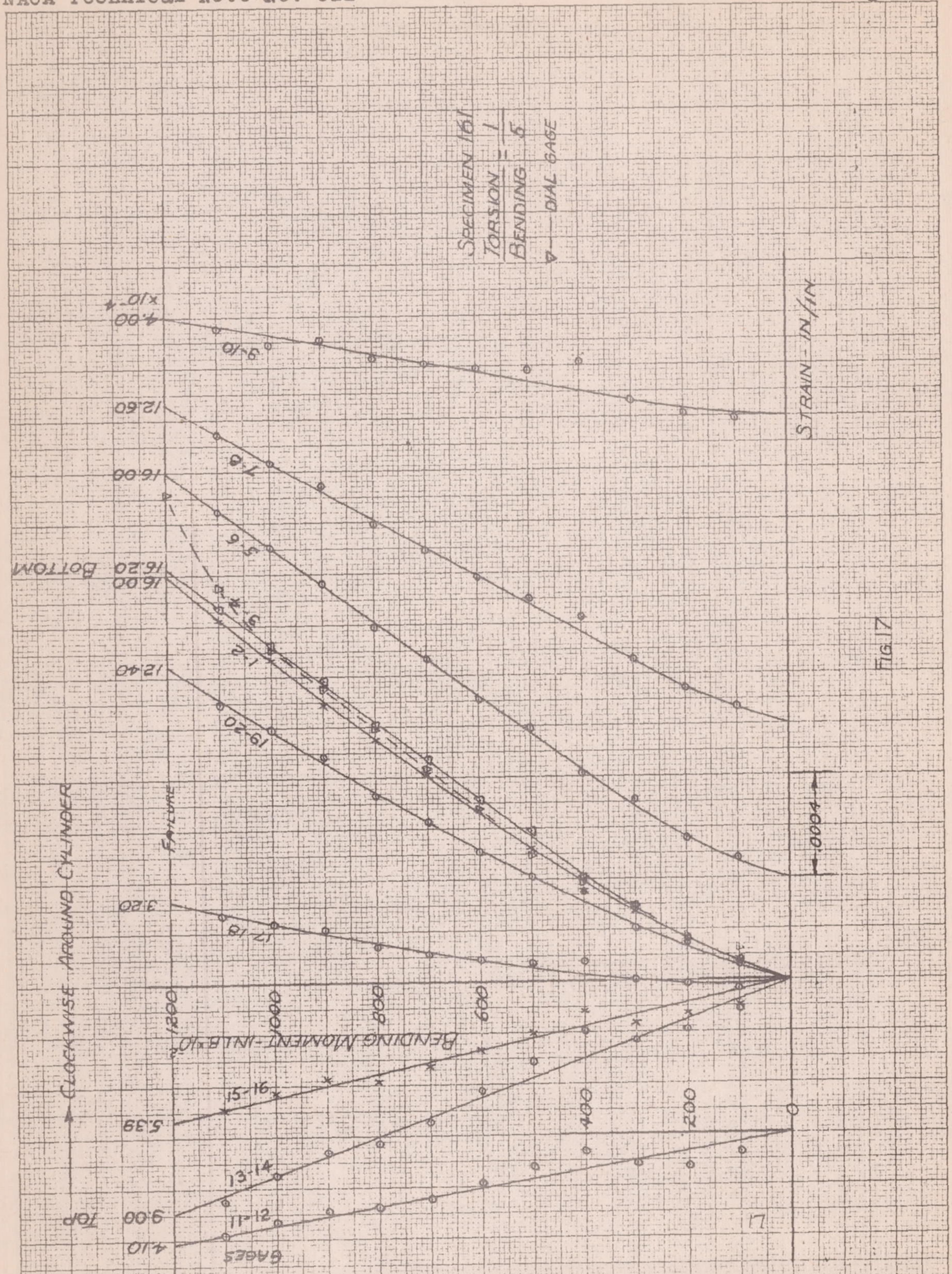

SPECIMEN 161
TORSION / BENDING = 1/5
▽ — DIAL GAGE
STRAIN - IN/IN
.0004
BENDING MOMENT - IN LB x10²
CLOCKWISE AROUND CYLINDER
TOP
BOTTOM
FAILURE
GAGES
9-10
7-8
5-6
3-4
1-2
19-20
17-18
15-16
13-14
11-12

FIG. 17

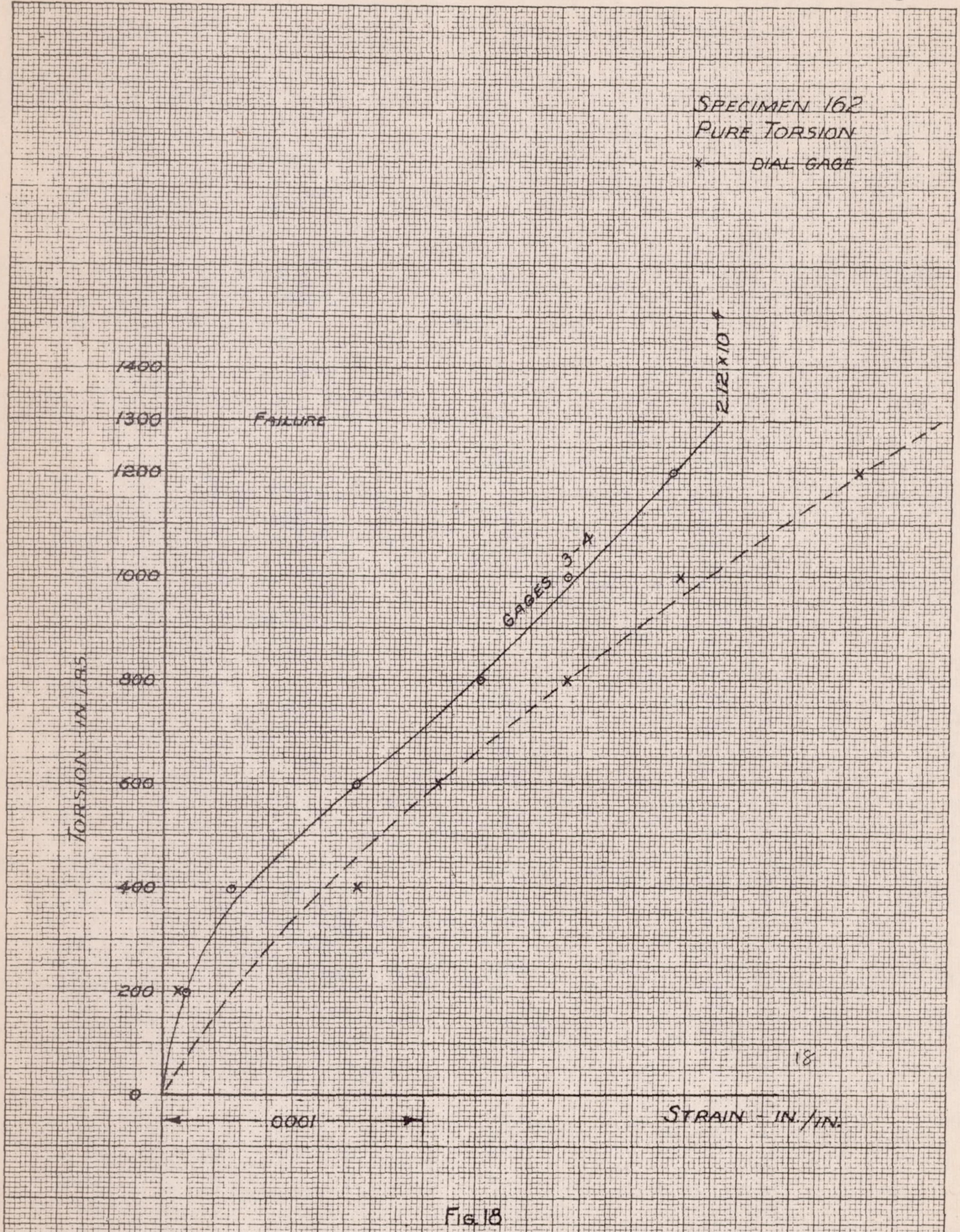

SPECIMEN 162
PURE TORSION
x—— DIAL GAGE
TORSION IN LBS
1400
1300
1200
1000
800
600
400
200
0
FAILURE
2.12 x 10⁻⁴
GAGES 3-4
.0001
STRAIN - IN./IN.
18

Fig. 18

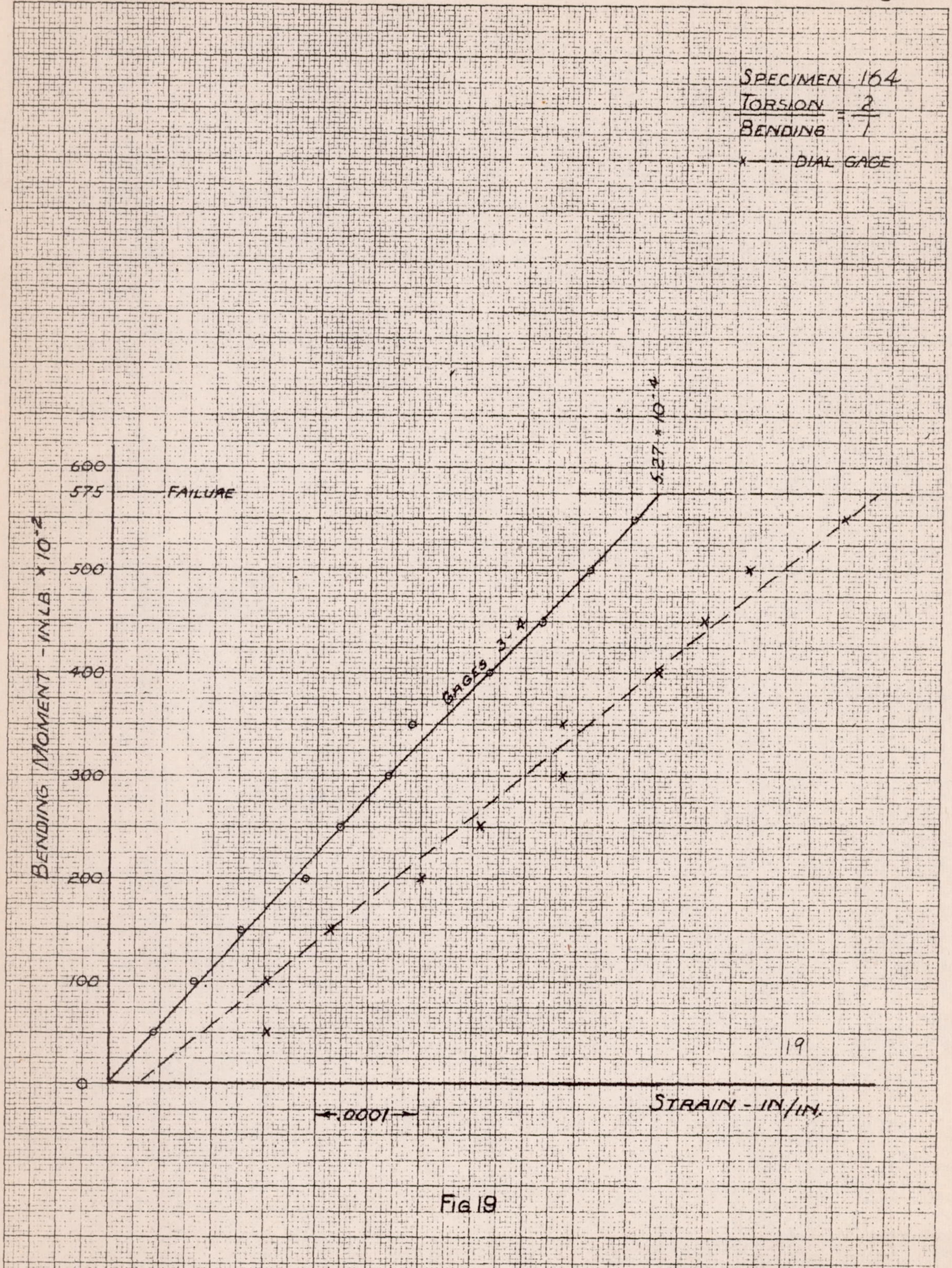

SPECIMEN 164
TORSION / BENDING = 2/1
x — — DIAL GAGE
BENDING MOMENT - IN.LB × 10⁻²
600
575
FAILURE
500
400
300
200
100
GAGES 3-4
5.27 × 10⁻⁴
19
STRAIN - IN./IN.
←.0001→

Fig 19

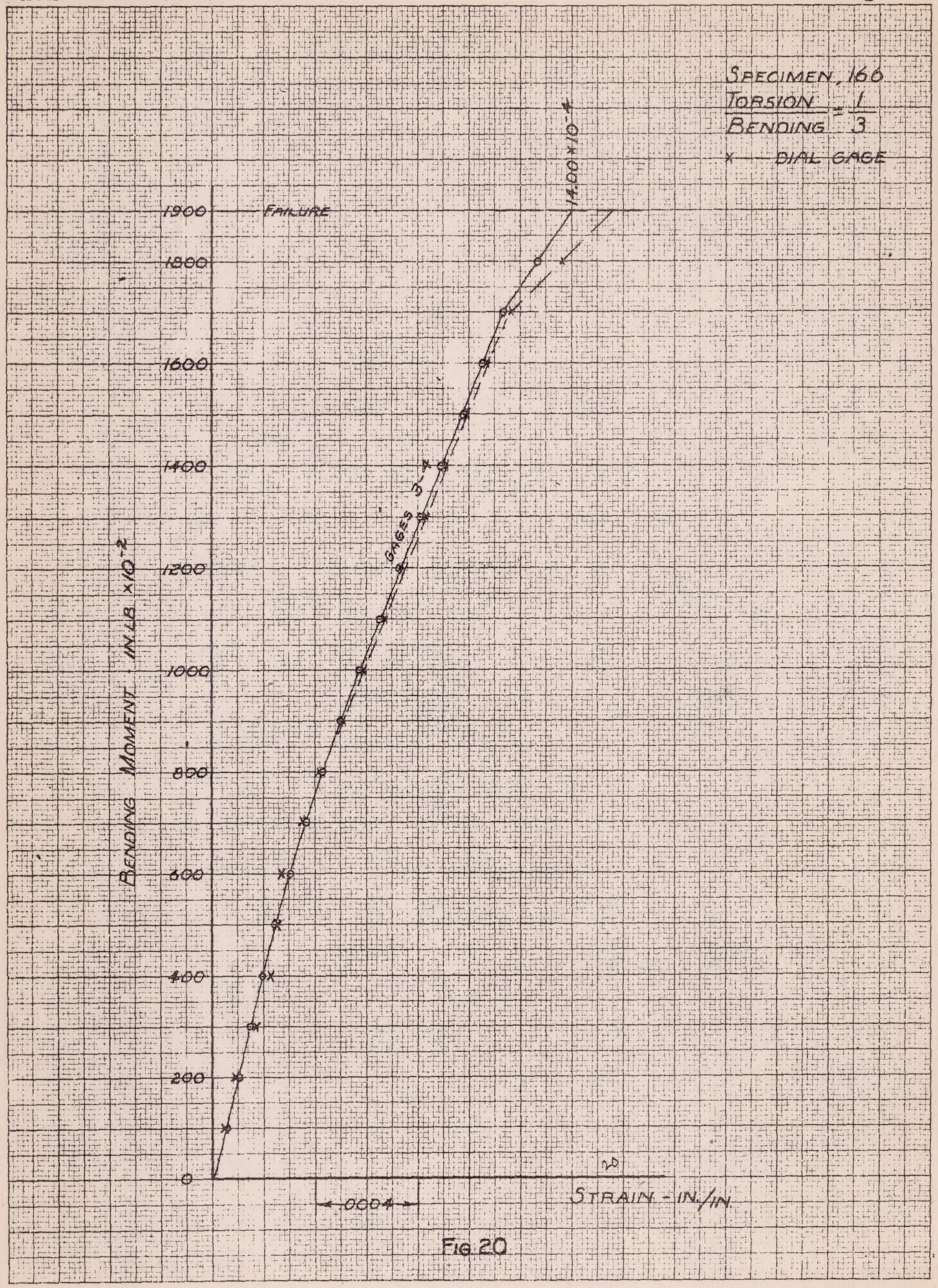

SPECIMEN, 166
TORSION / BENDING = 1/3
x --- DIAL GAGE
1900 FAILURE
14.00×10⁻⁴
1800
1600
1400
GAGES 3-4
1200
1000
800
600
400
200
0
BENDING MOMENT - IN.LB ×10⁻²
.0004
STRAIN - IN./IN.

Fig. 20

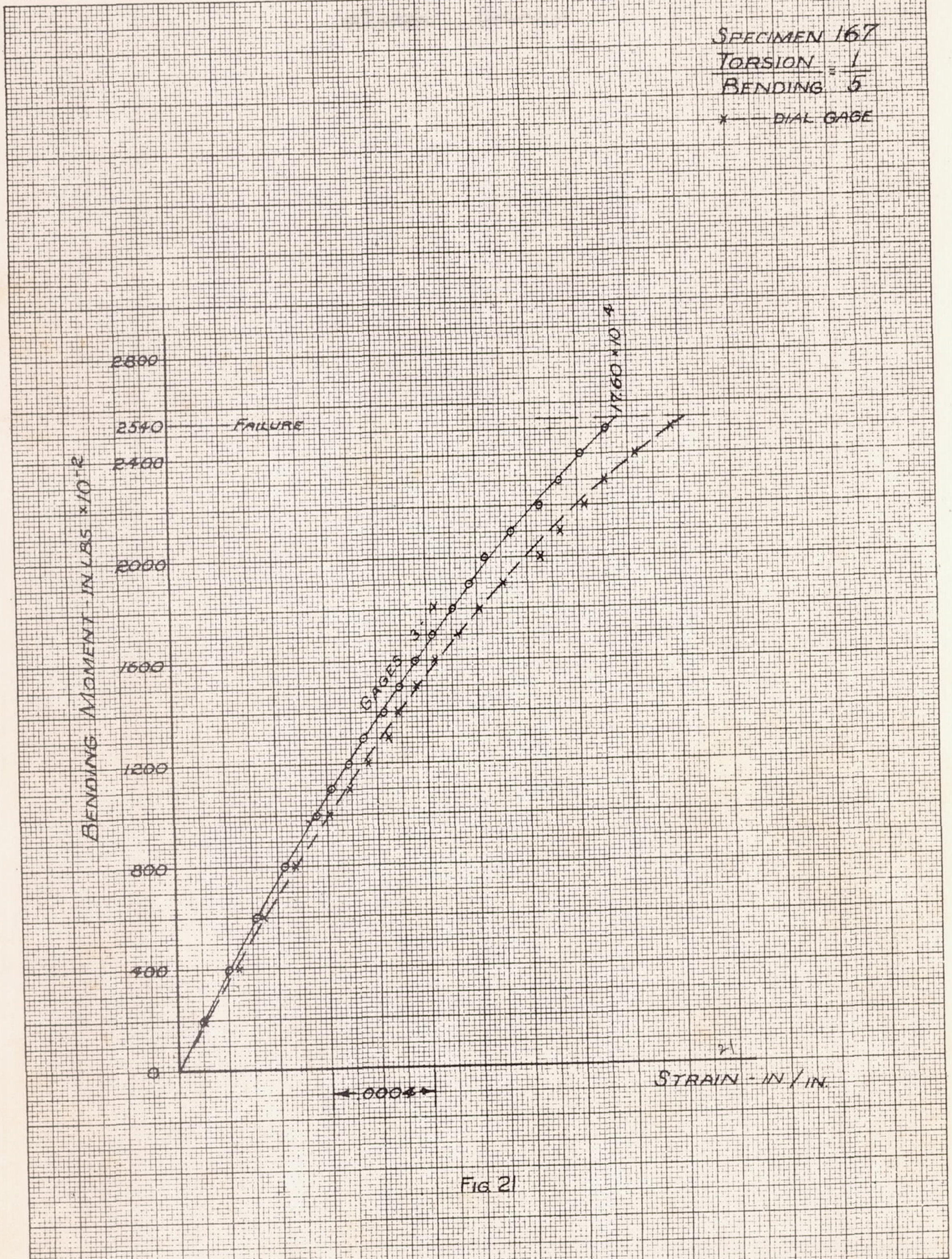

SPECIMEN 167
TORSION / BENDING = 1/5
—— DIAL GAGE
BENDING MOMENT - IN LBS × 10^-2
2800
2540
2400
2000
1600
1200
800
400
0
FAILURE
GAGES 3
17.60 × 10^-4
STRAIN - IN / IN.
.0004

FIG 21

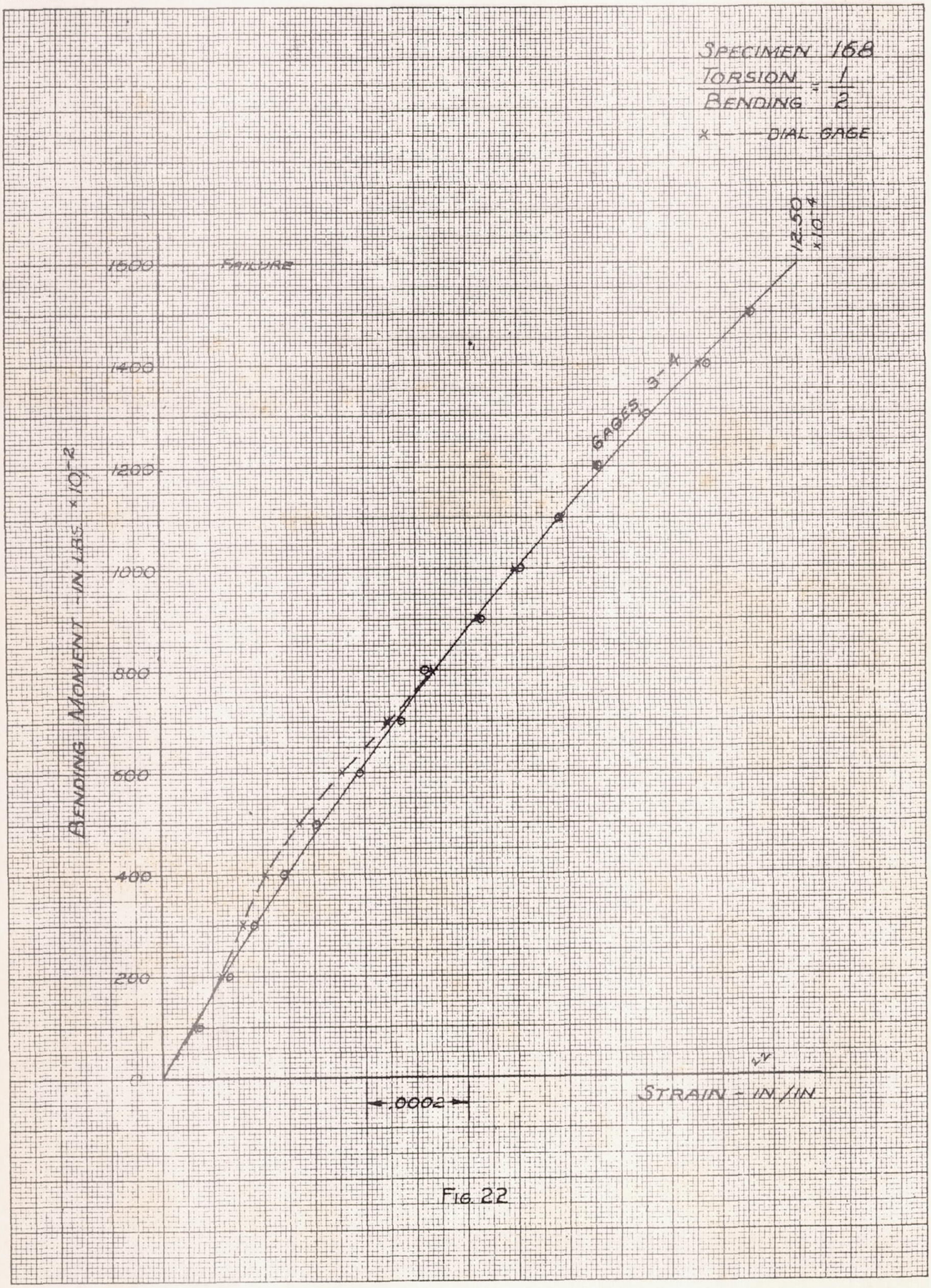

SPECIMEN 168
TORSION / BENDING = 1/2
× —— DIAL GAGE
12.50 ×10⁻⁴
FAILURE
GAGES 3-4
1600
1400
1200
1000
800
600
400
200
0
BENDING MOMENT - IN LBS × 10⁻²
.0002
STRAIN - IN./IN.

FIG. 22

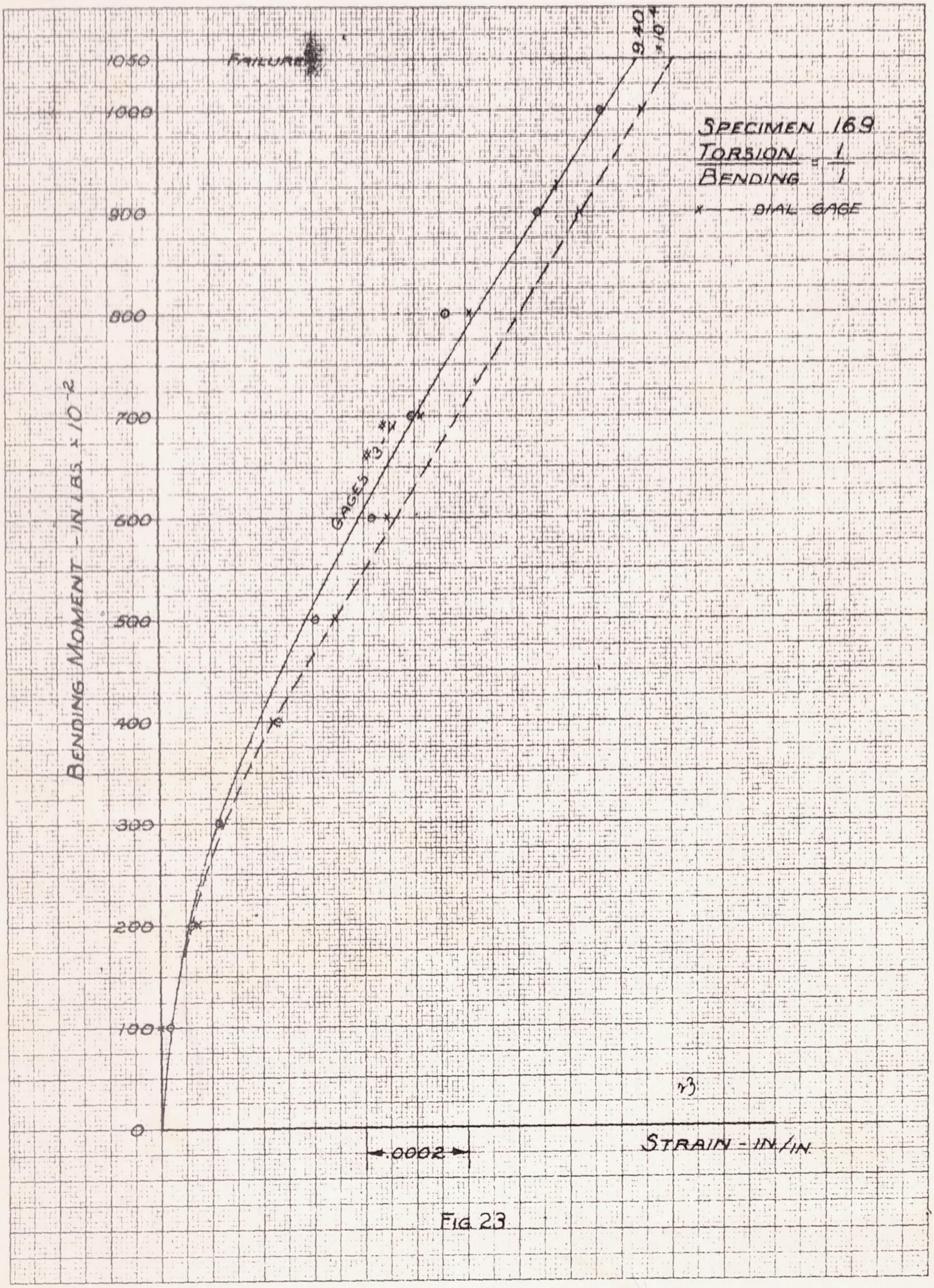

1050
FAILURE
1000
900
800
700
600
500
400
300
200
100
0
BENDING MOMENT - IN LBS x 10^-2
940 x 10^-4
SPECIMEN 169
TORSION / BENDING = 1/1
x — — DIAL GAGE
GAGES #3-#4
.0002
STRAIN - IN/IN.

Fig 23

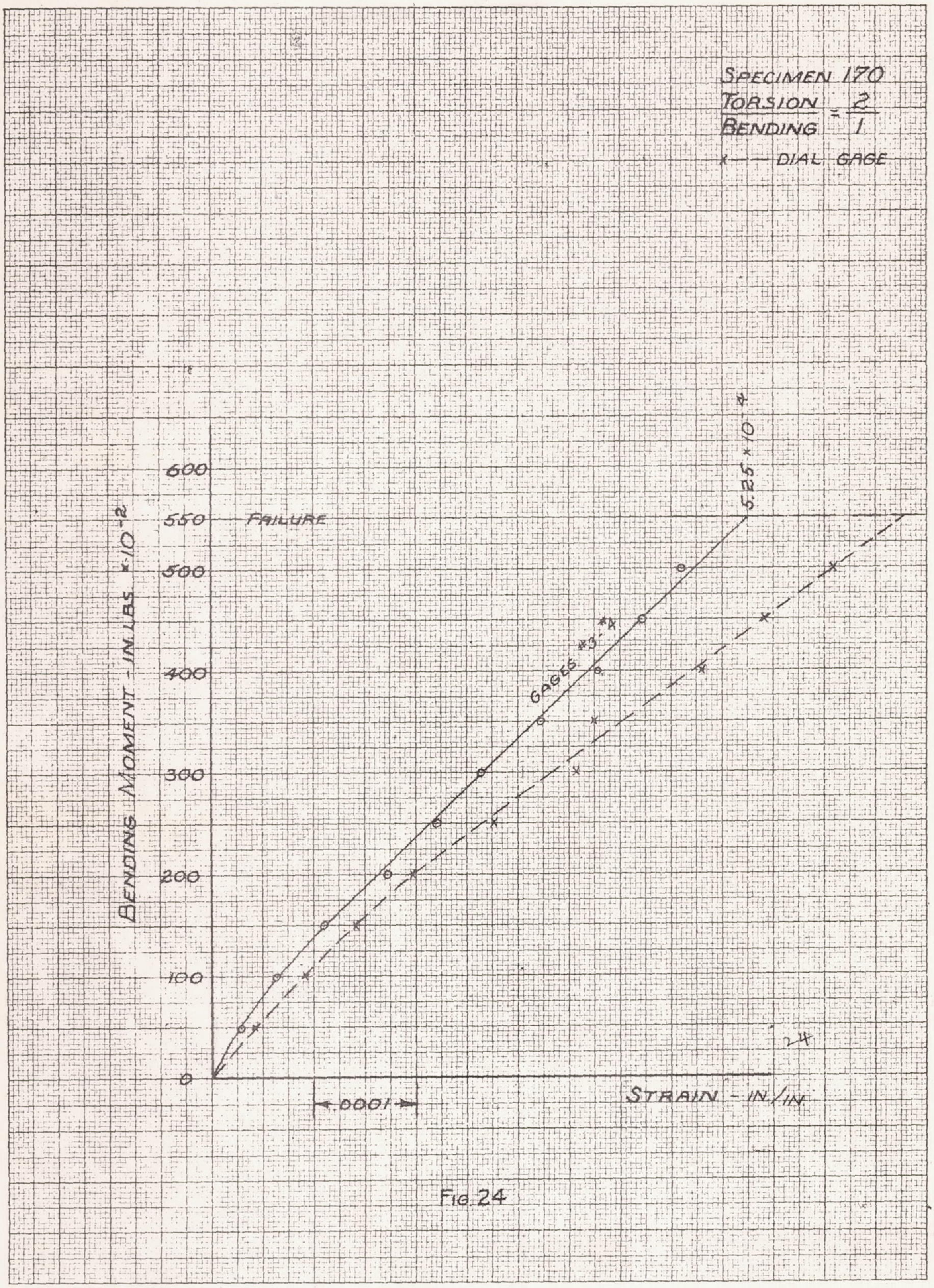

SPECIMEN 170
TORSION / BENDING = 2 / 1
x --- DIAL GAGE
BENDING MOMENT - IN. LBS. × 10^-2
600
550
FAILURE
500
400
300
200
100
0
5.25 × 10^-4
GAGES #3 - #4
STRAIN - IN/IN
.0001
24

Fig. 24

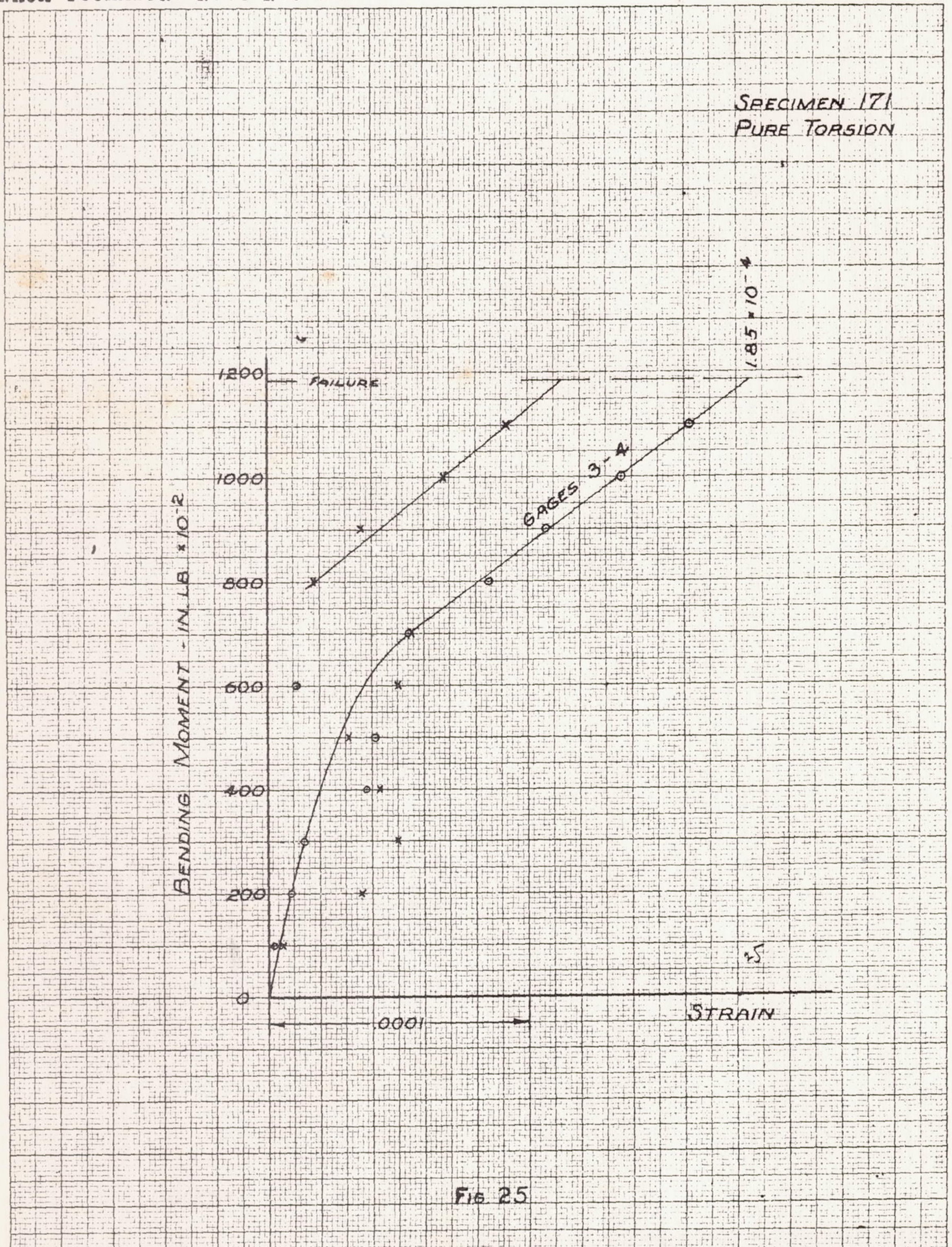

SPECIMEN 171
PURE TORSION
1200
FAILURE
1000
800
600
400
200
0
BENDING MOMENT - IN. LB × 10⁻²
GAGES 3-4
1.85 × 10⁻⁴
.0001
STRAIN

Fig 25

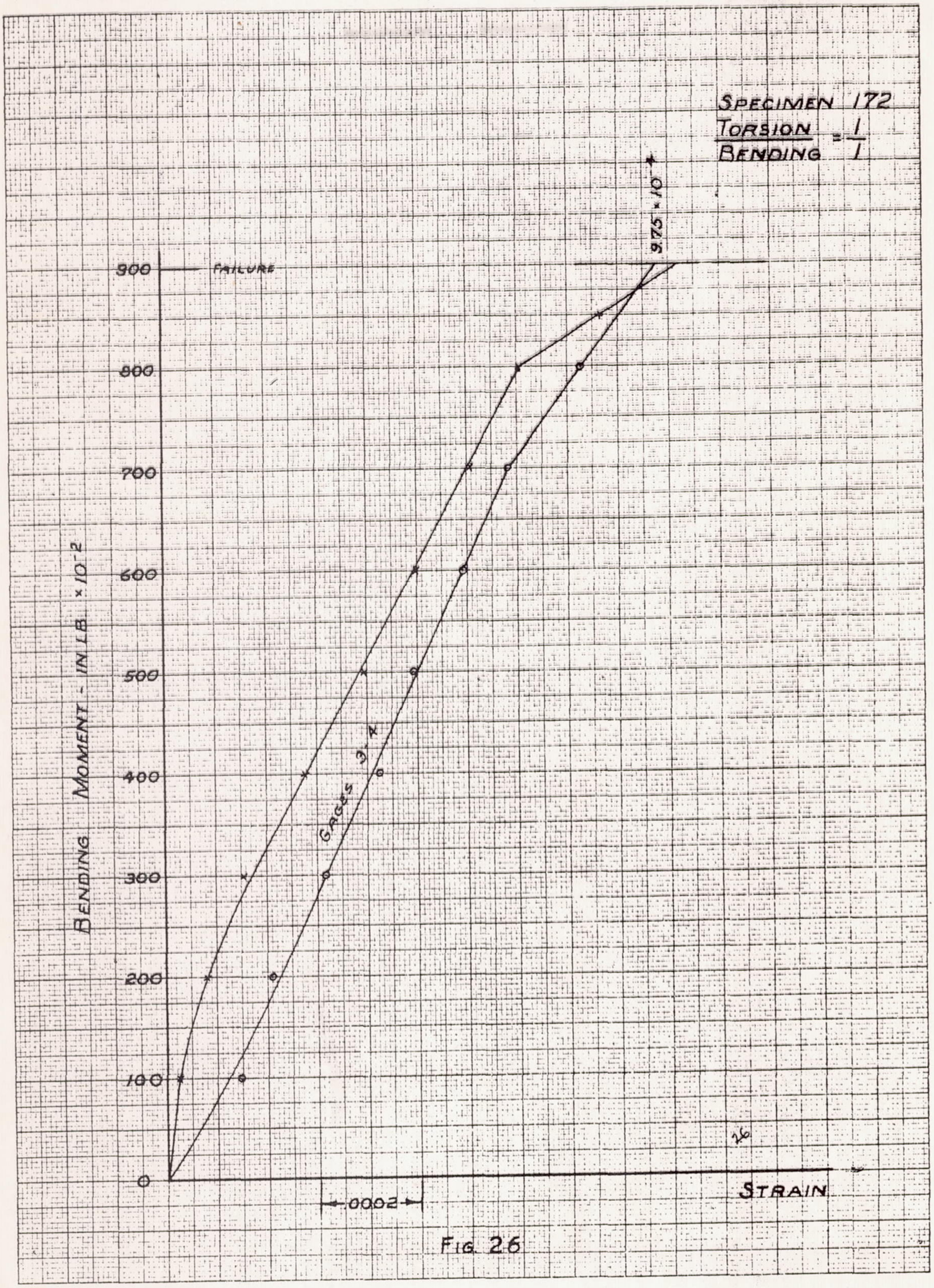

SPECIMEN 172
TORSION / BENDING = 1/1
9.75 × 10⁻⁴
900
FAILURE
800
700
600
500
400
300
200
100
0
BENDING MOMENT - IN LB. × 10⁻²
GAGES 3, 4
.0002
STRAIN

FIG. 26

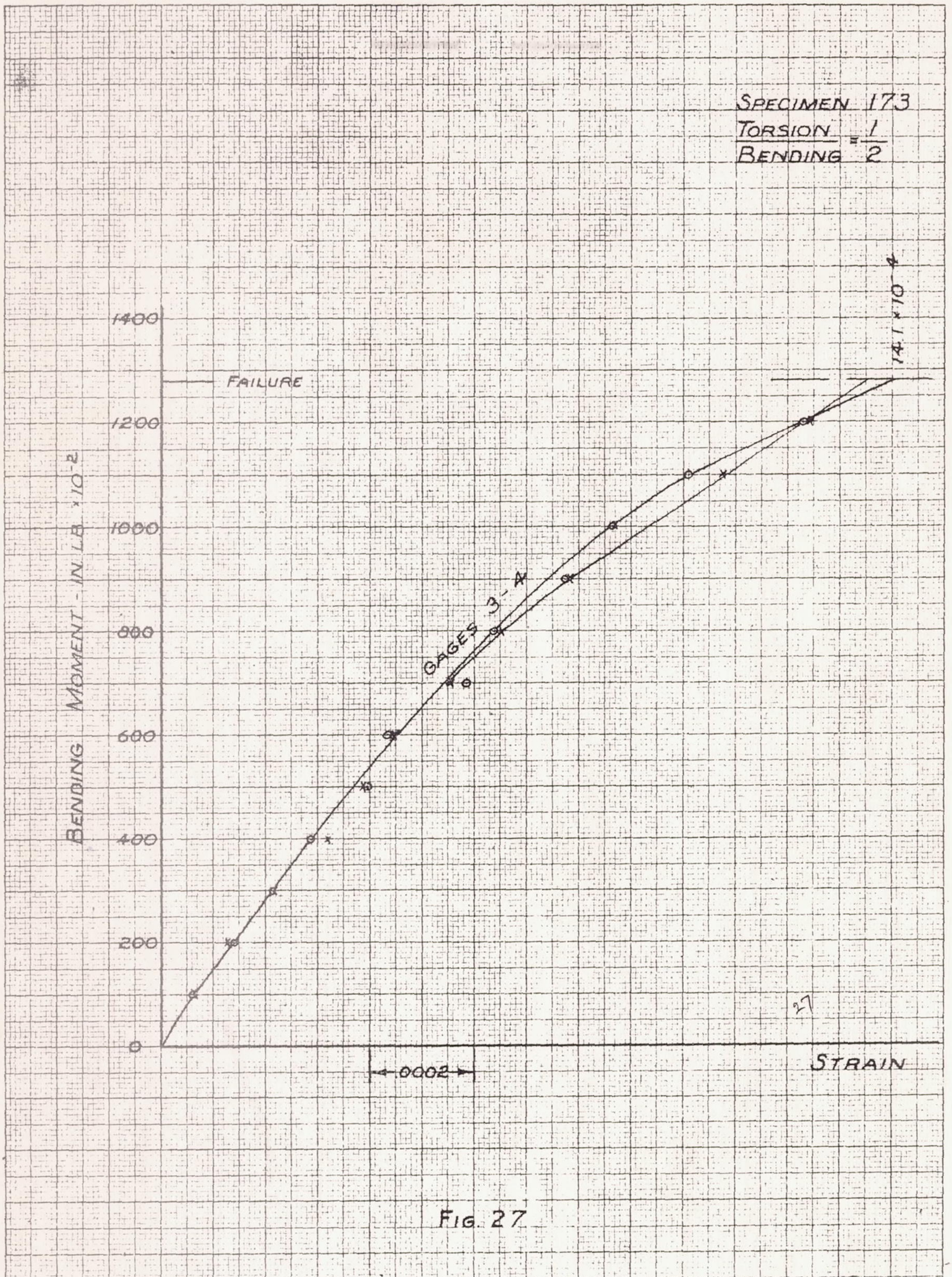

SPECIMEN 173
TORSION / BENDING = 1/2
BENDING MOMENT - IN LB × 10^-2
1400
1200
1000
800
600
400
200
0
FAILURE
14.1 × 10^-4
GAGES 3-4
STRAIN
.0002
27

FIG. 27

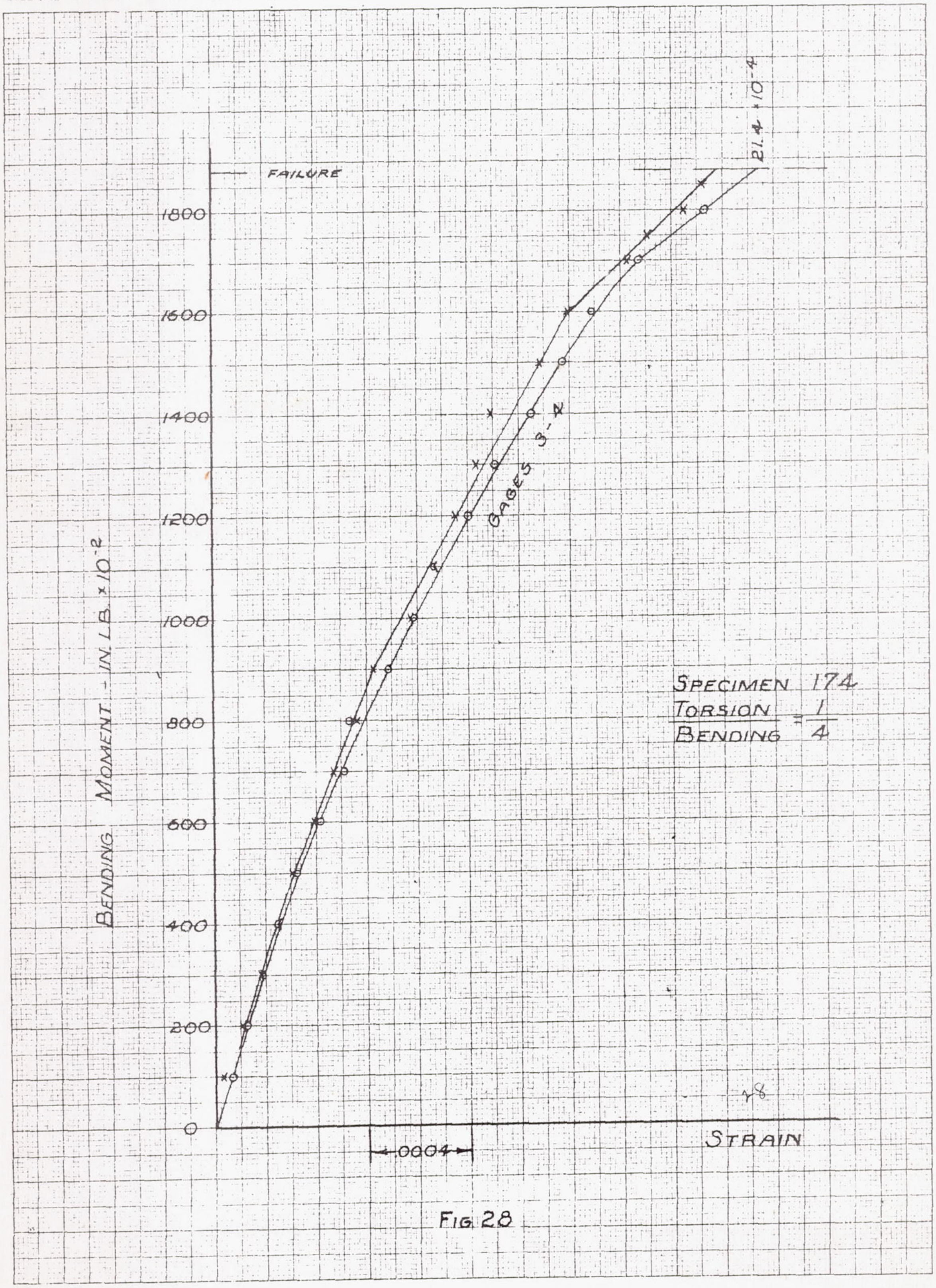

FAILURE
1800
1600
1400
1200
1000
800
600
400
200
0
BENDING MOMENT - IN. LB. x 10^-2
21.4 x 10^-4
GAGES 3-R
SPECIMEN 174
TORSION / BENDING = 1/4
.0004
STRAIN
28

FIG 28

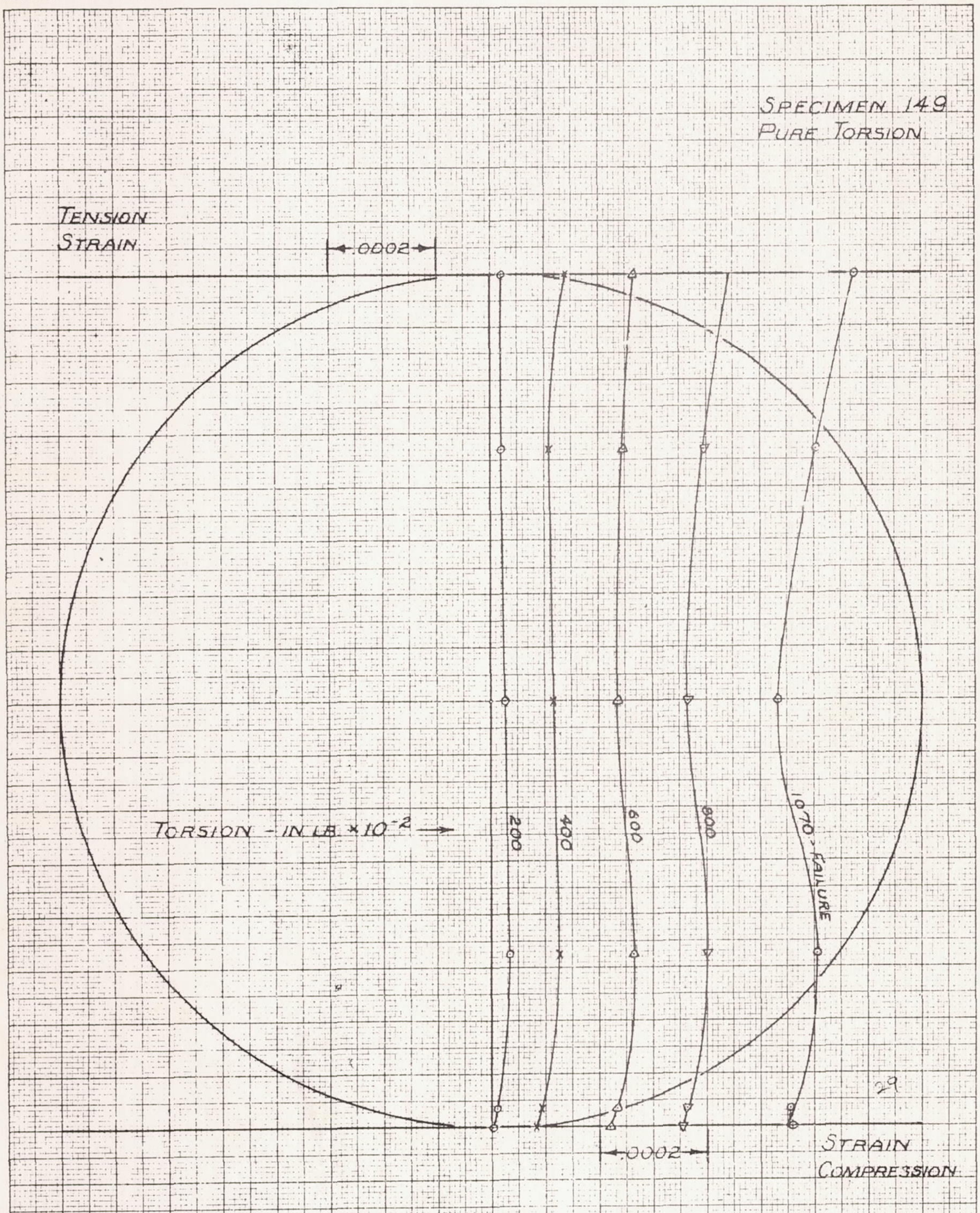

SPECIMEN 149
PURE TORSION
TENSION
STRAIN
.0002
TORSION - IN LB. × 10⁻²
200
400
600
800
1070 - FAILURE
.0002
STRAIN
COMPRESSION

FIG. 29

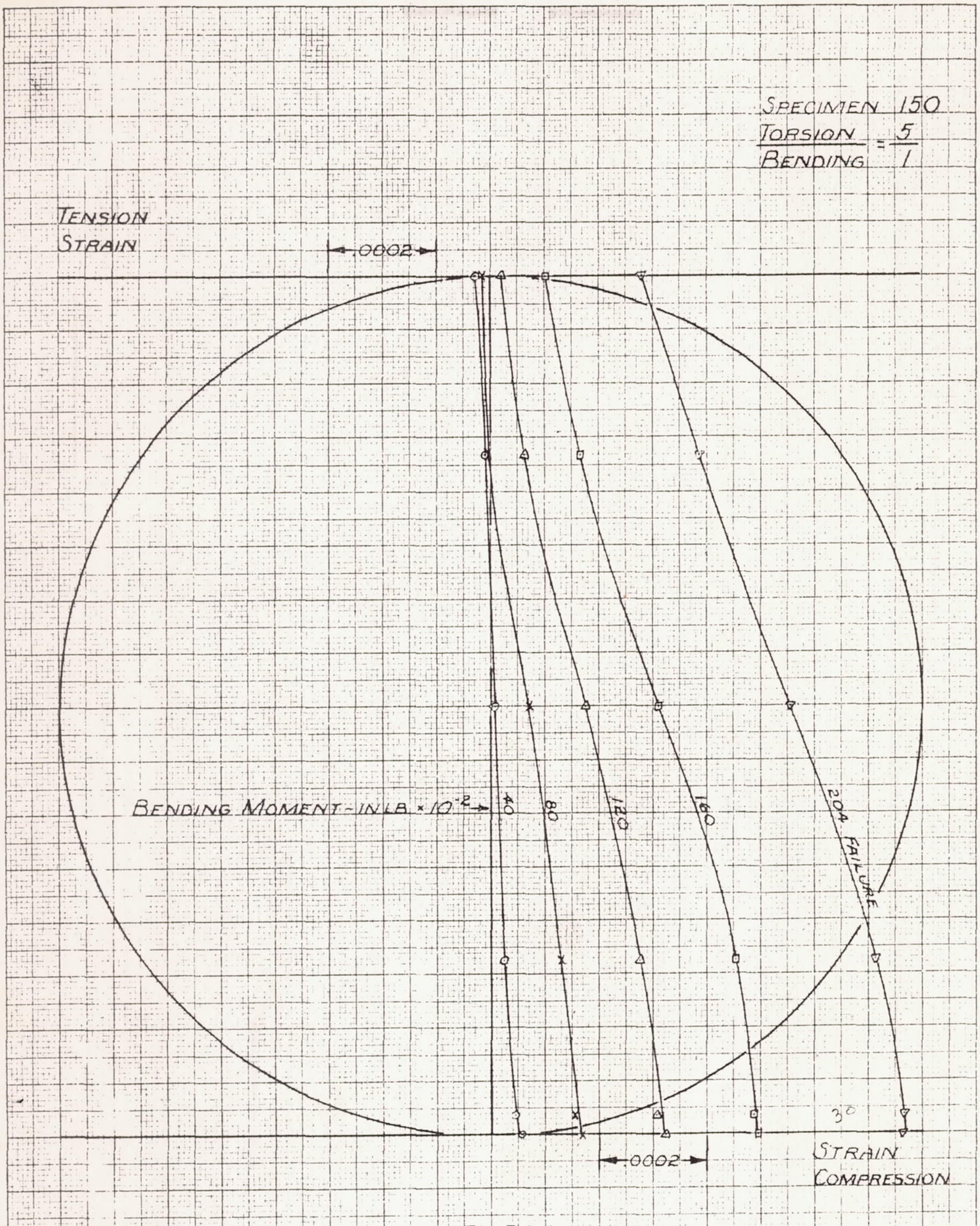

SPECIMEN 150
TORSION / BENDING = 5 / 1
TENSION STRAIN
.0002
BENDING MOMENT - IN LB × 10⁻²
40
80
120
160
204 FAILURE
.0002
STRAIN COMPRESSION

FIG. 30

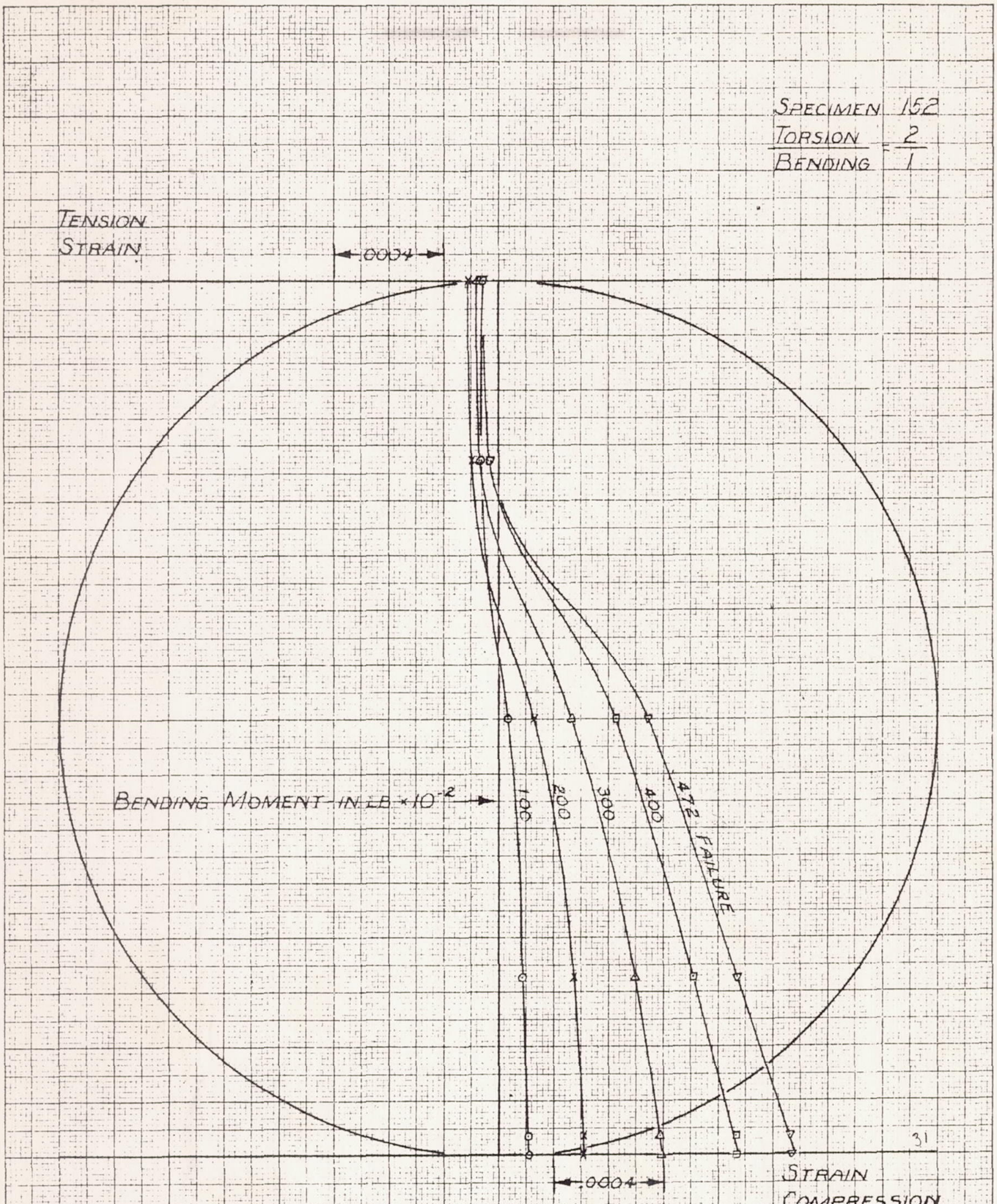

SPECIMEN 152
TORSION / BENDING = 2/1
TENSION STRAIN
.0004
BENDING MOMENT IN LB × 10^-2
100
200
300
400
472 FAILURE
31
.0004
STRAIN COMPRESSION

FIG. 31

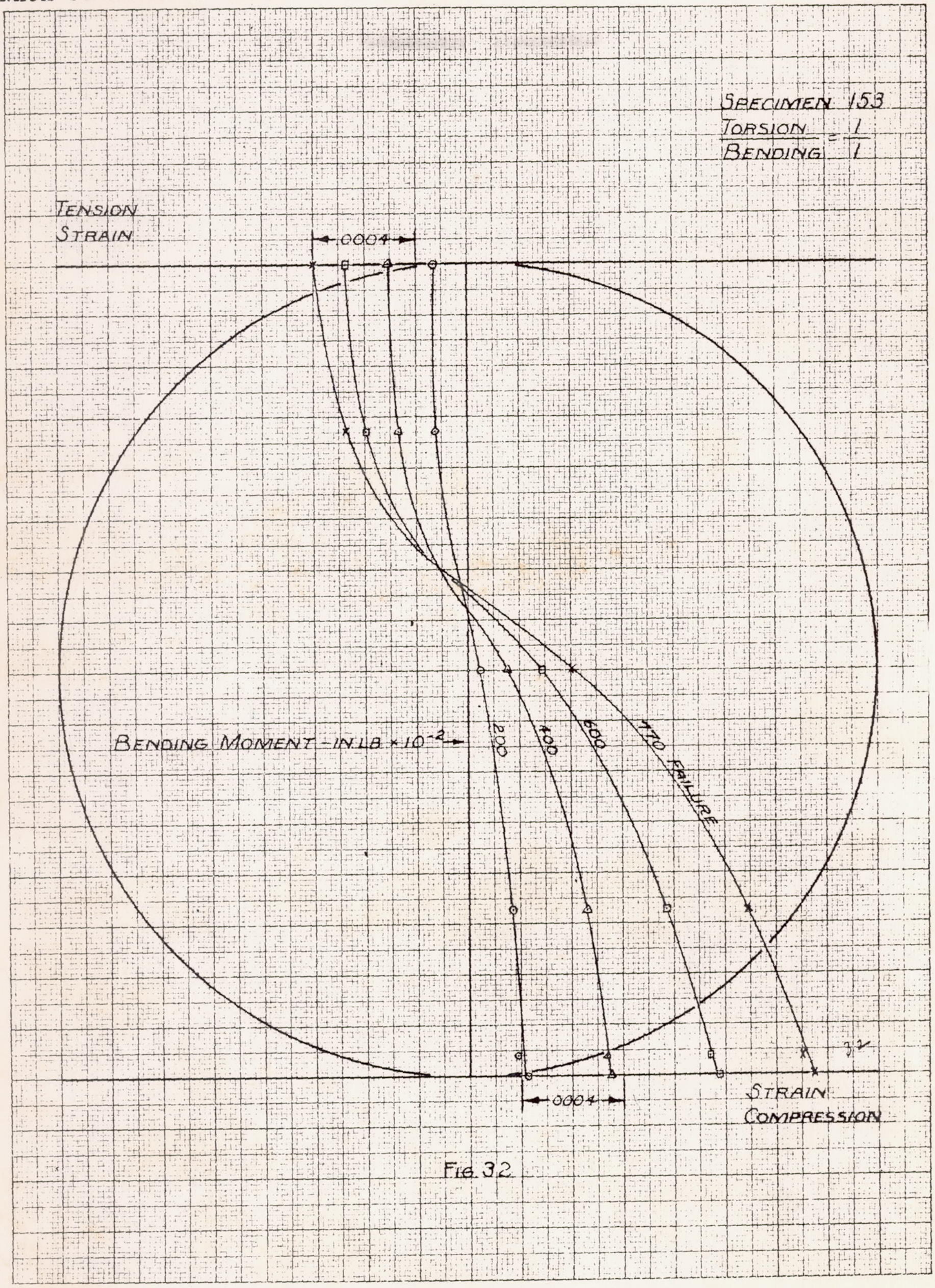

SPECIMEN 153
TORSION / BENDING = 1/1
TENSION STRAIN
.0004
BENDING MOMENT - IN LB × 10^-2
200
400
600
770 FAILURE
.0004
STRAIN COMPRESSION

Fig. 32

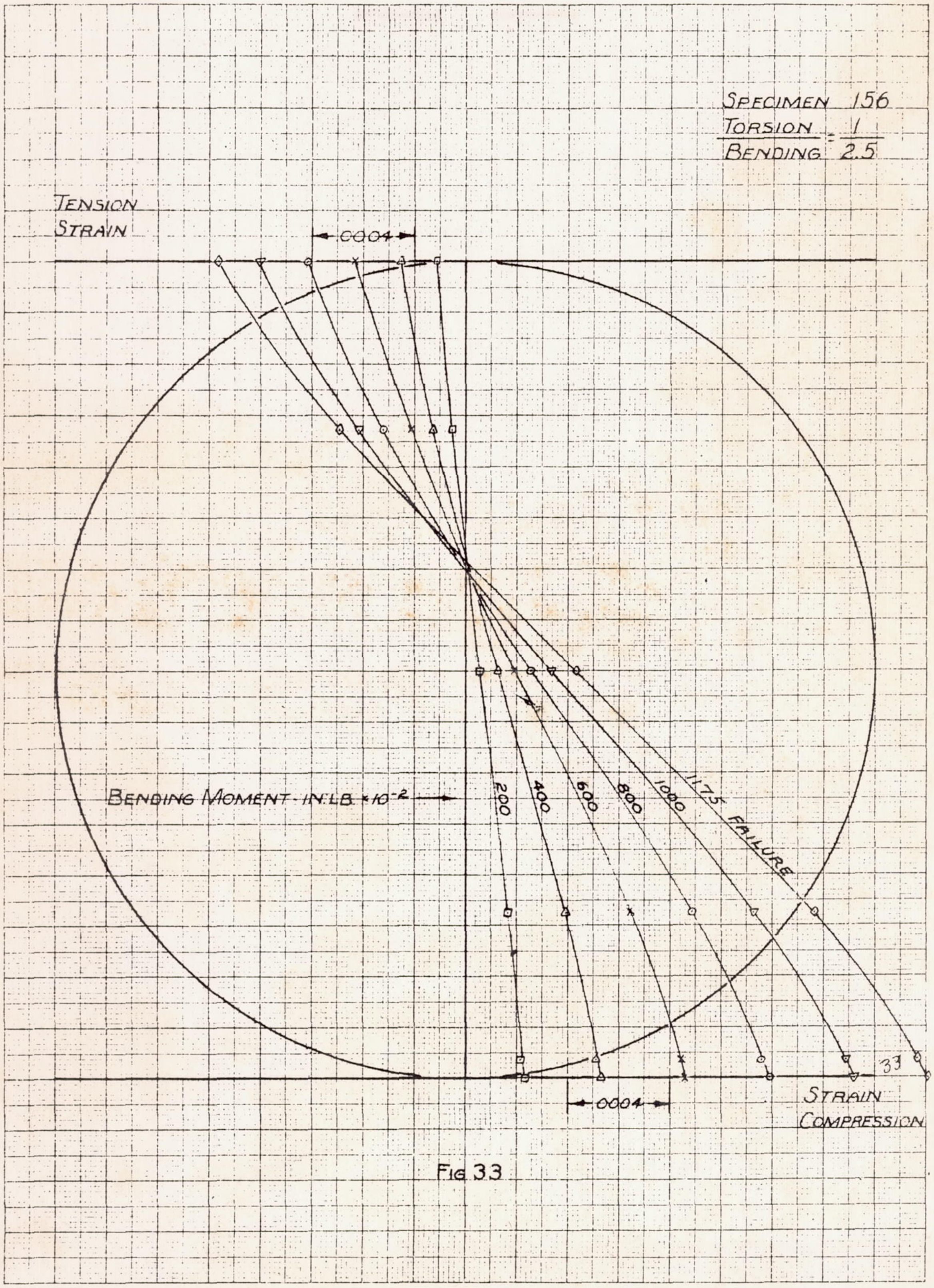

SPECIMEN 156
TORSION / BENDING = 1 / 2.5
TENSION STRAIN
.0004
BENDING MOMENT - IN.LB. × 10^-2
200
400
600
800
1000
1175 FAILURE
.0004
STRAIN COMPRESSION

FIG. 33

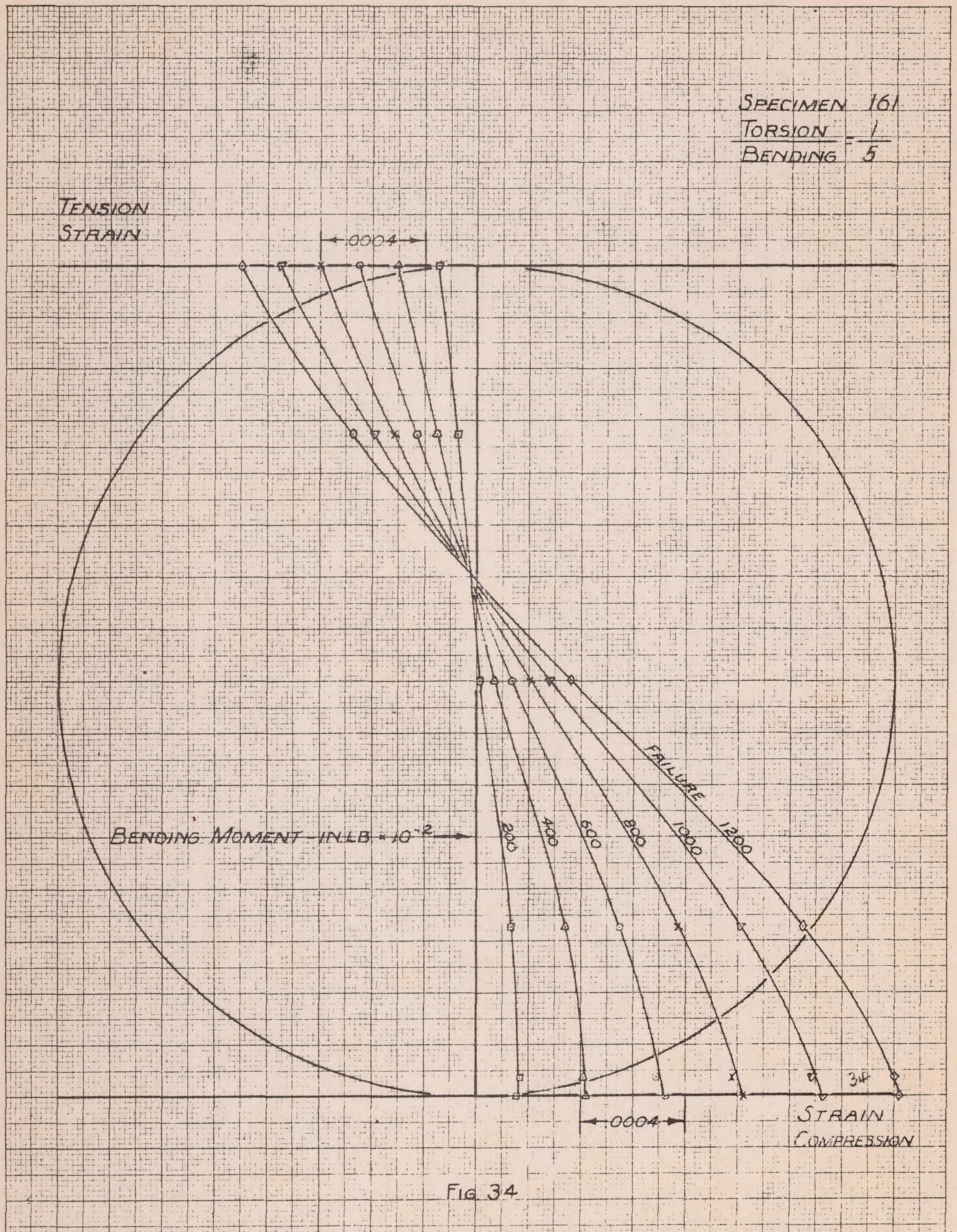

SPECIMEN 161
TORSION / BENDING = 1/5
TENSION
STRAIN
.0004
FAILURE
200
400
600
800
1000
1200
BENDING MOMENT - IN.LB × 10^-2
.0004
STRAIN
COMPRESSION

FIG. 34

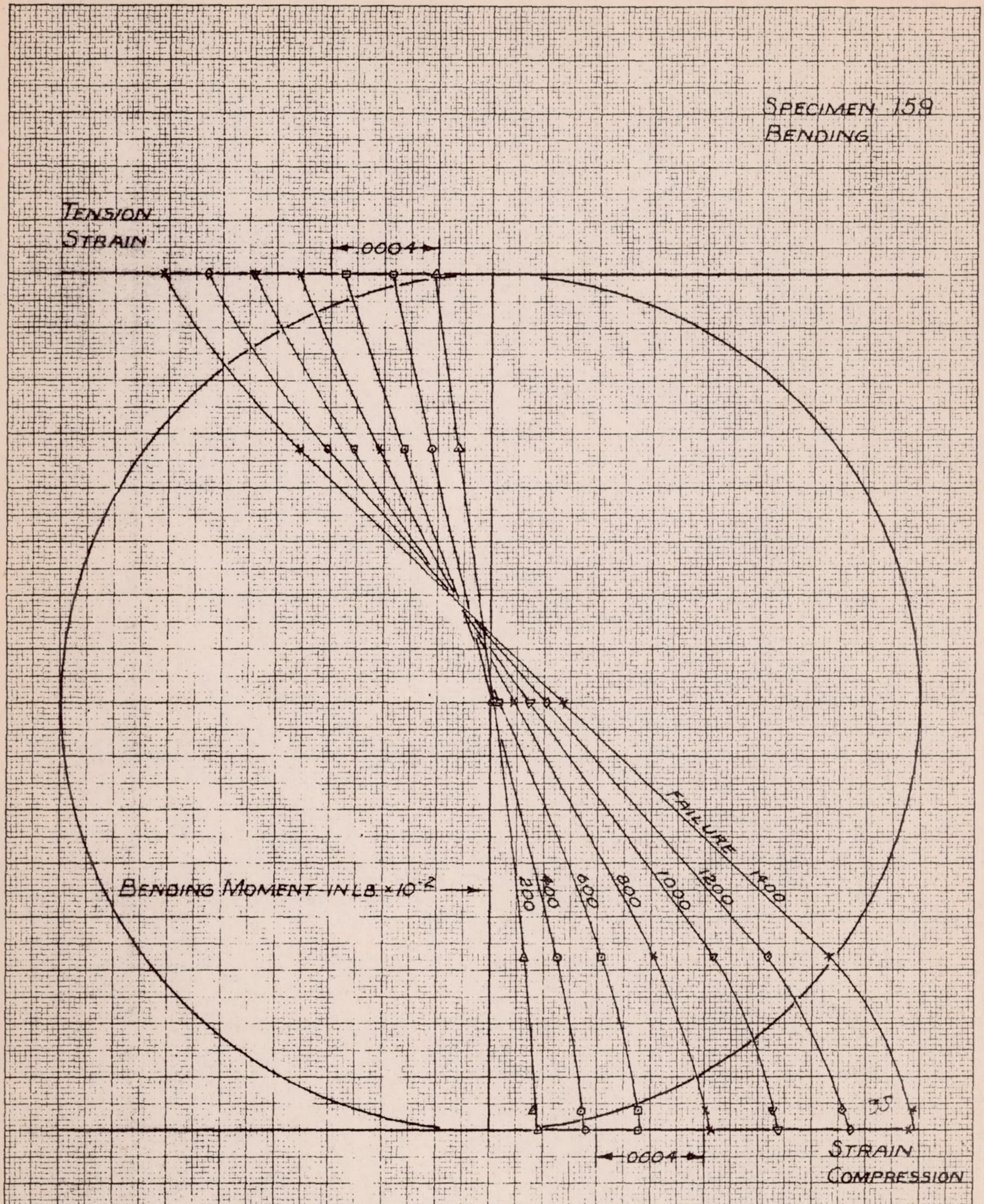

SPECIMEN 159
BENDING
TENSION
STRAIN
.0004
BENDING MOMENT IN LB × 10^-2
FAILURE
200
400
600
800
1000
1200
1400
STRAIN
COMPRESSION
.0004

FIG. 35

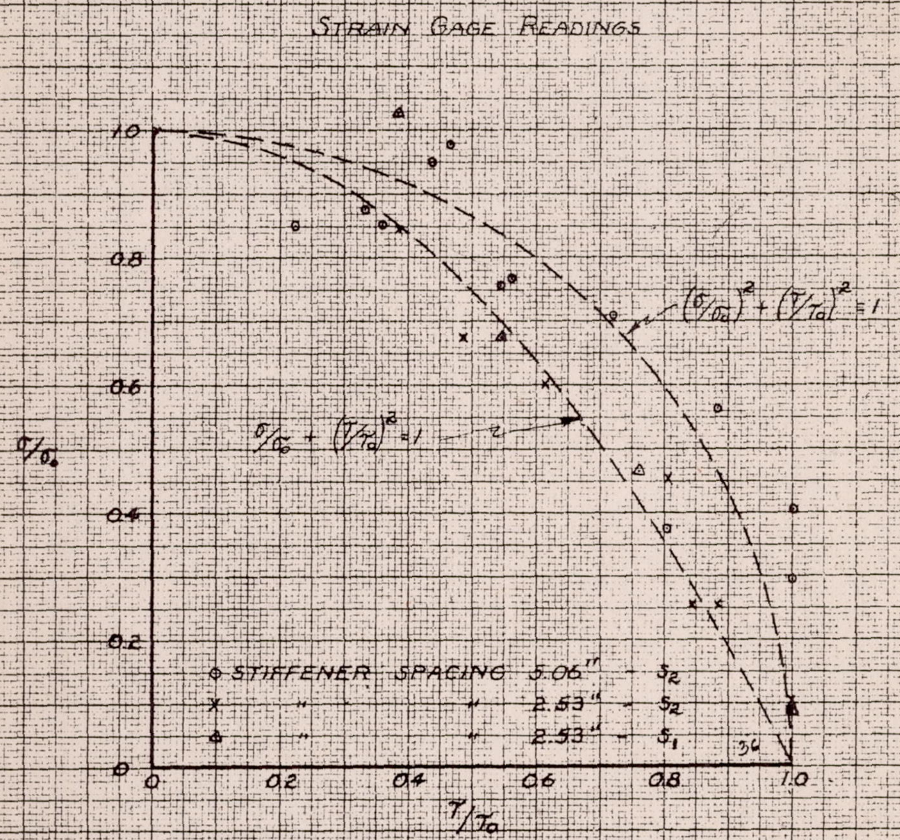

STRAIN GAGE READINGS
$(\sigma/\sigma_0)^2 + (\tau/\tau_0)^2 = 1$
$\sigma/\sigma_0 + (\tau/\tau_0)^2 = 1$
σ/σ_0
τ/τ_0
1.0
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1.0
○ STIFFENER SPACING 5.06" - S_2
× " " 2.53" - S_2
△ " " 2.53" - S_1

FIG. 36

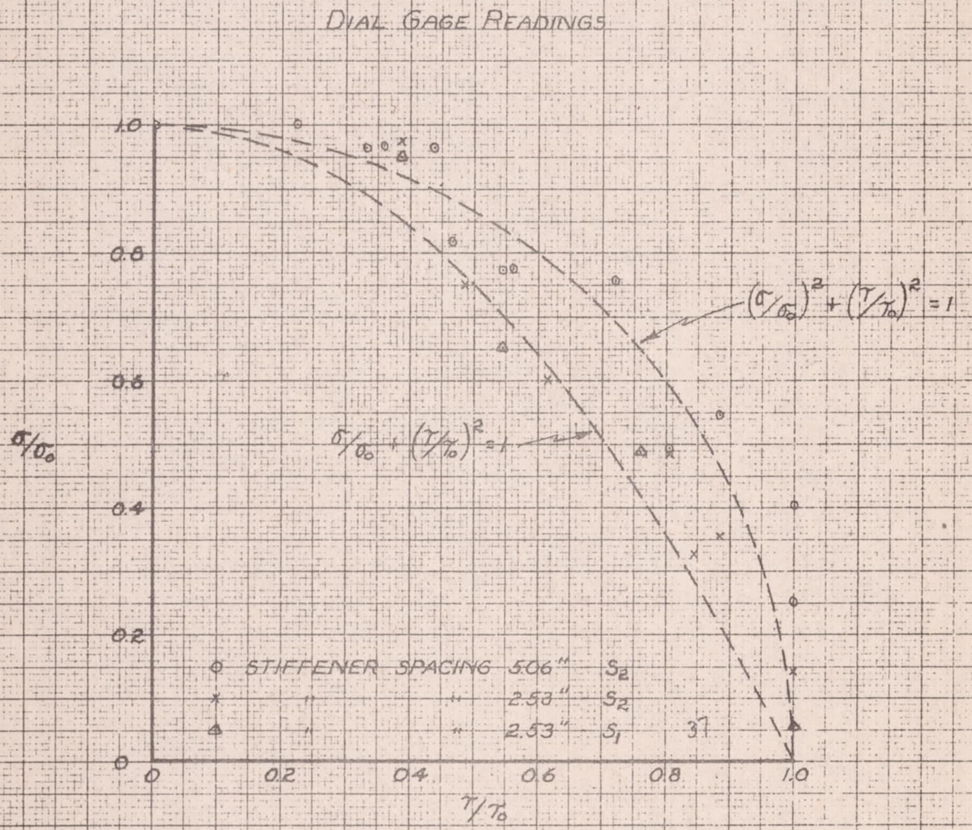

DIAL GAGE READINGS
1.0
0.8
0.6
0.4
0.2
0
σ/σ_0
$(\sigma/\sigma_0)^2 + (\tau/\tau_0)^2 = 1$
$\sigma/\sigma_0 + (\tau/\tau_0)^2 = 1$
STIFFENER SPACING 5.06" S_2
" " 2.53" S_2
" " 2.53" S_1
0 0.2 0.4 0.6 0.8 1.0
τ/τ_0

FIG. 37

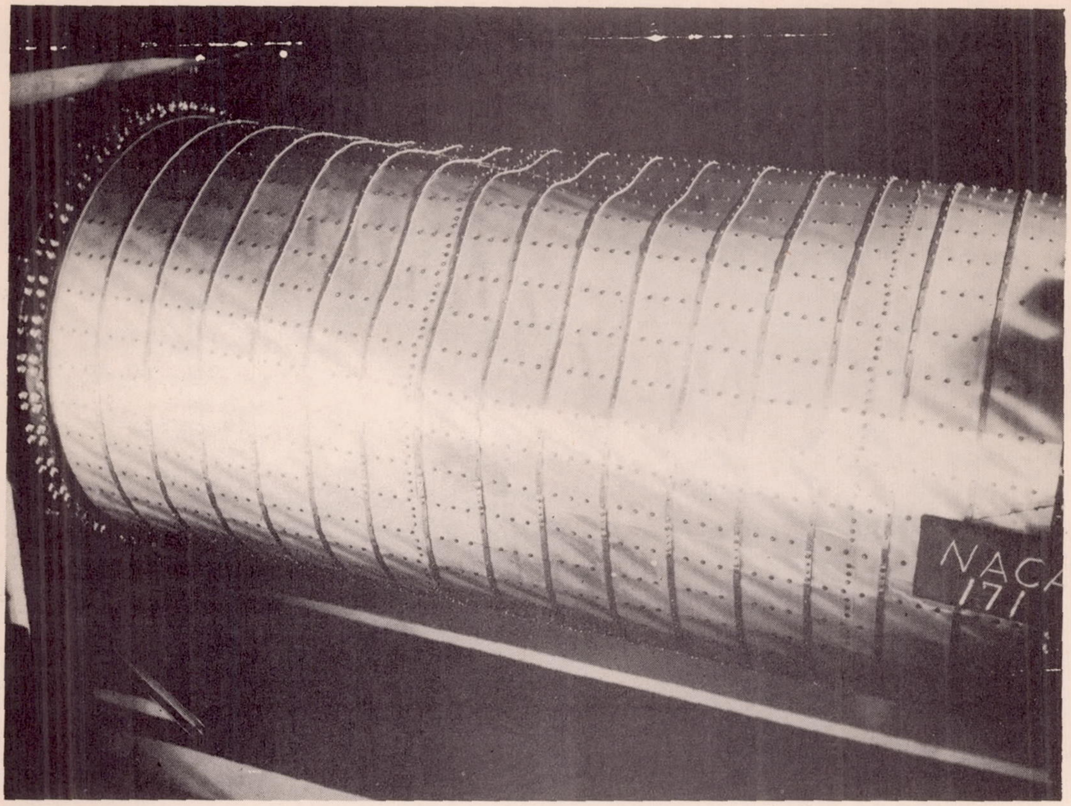


Figure 38.- Pure torsion.

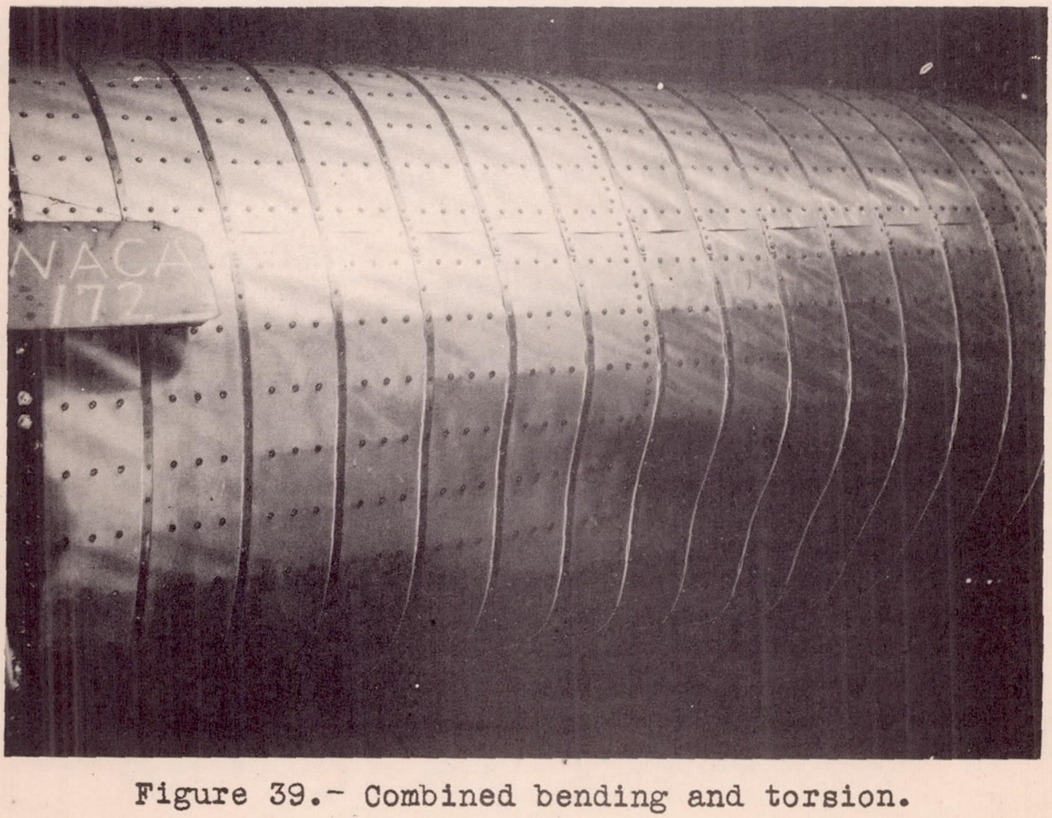


Figure 39.- Combined bending and torsion.

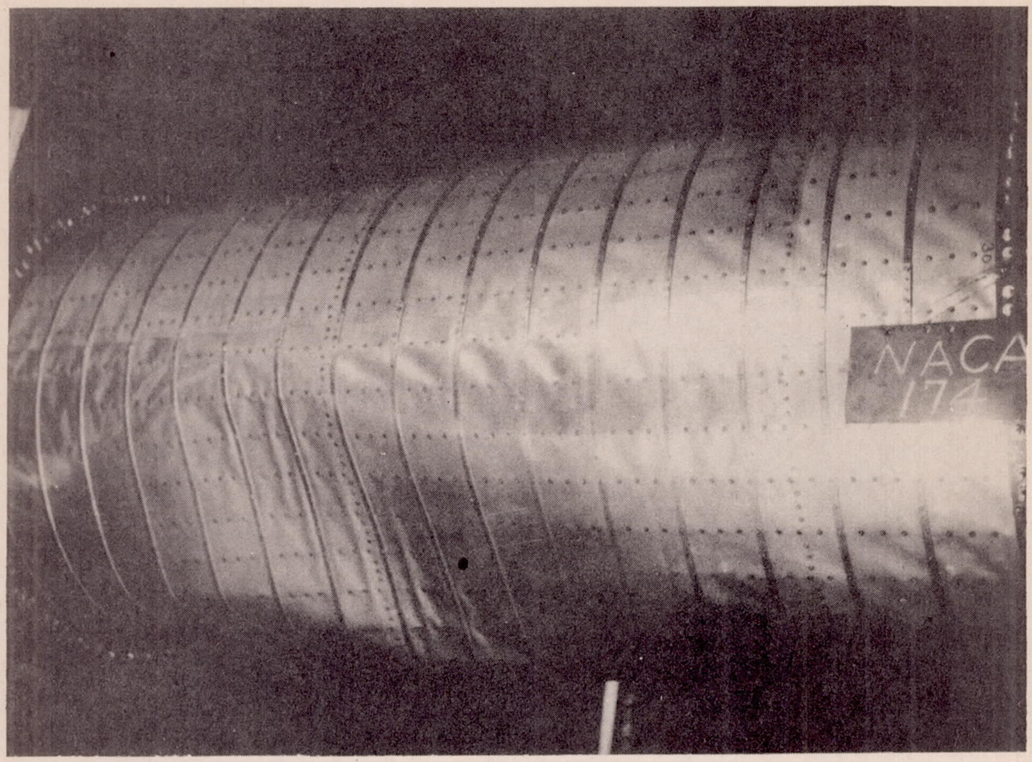


Figure 40.- Combined bending and torsion.

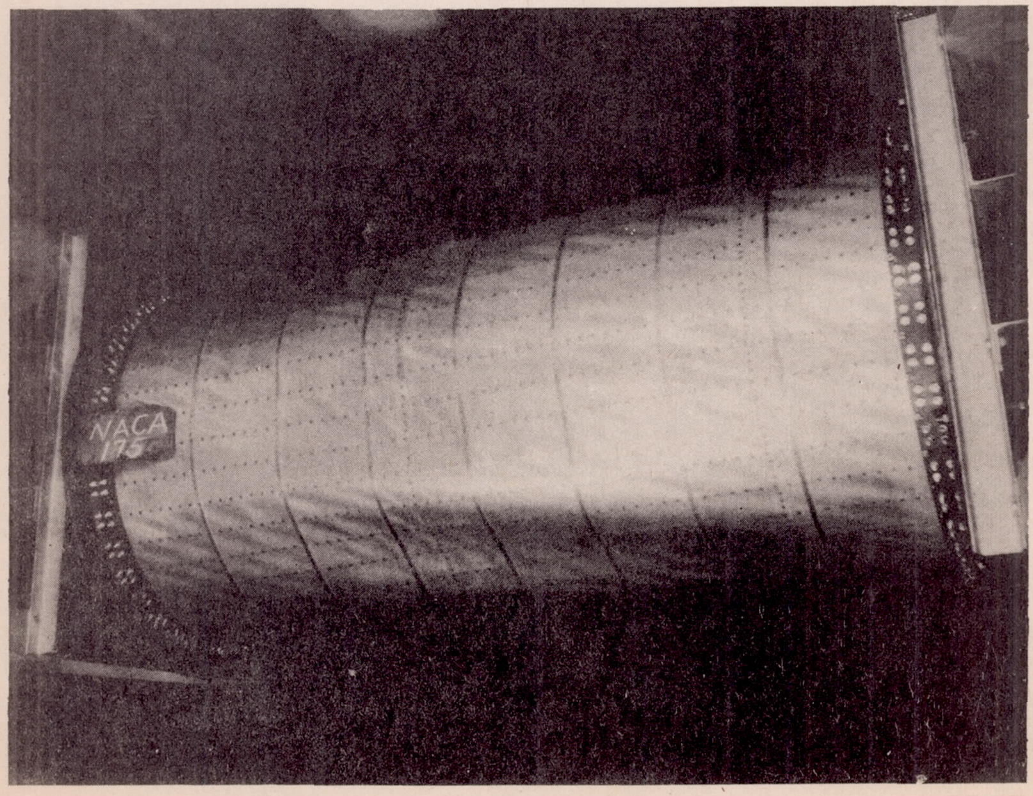


Figure 41.- Pure torsion.

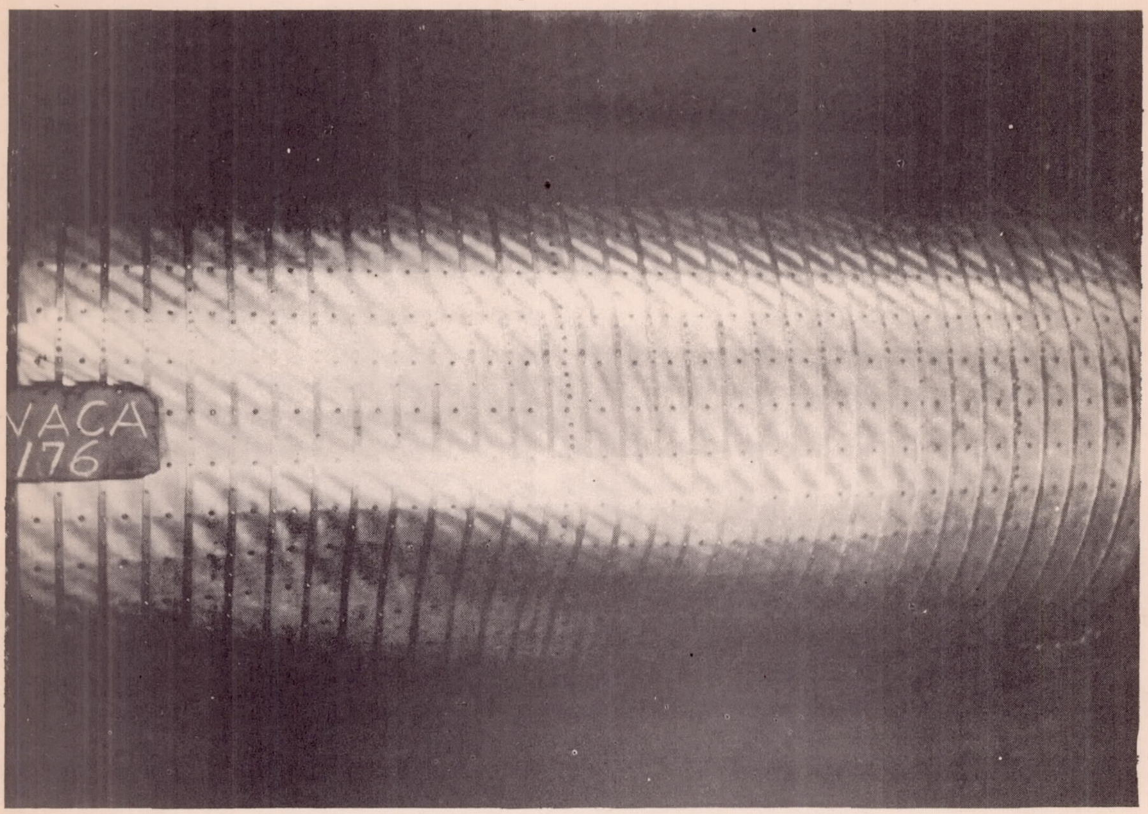


Figure 42.- Pure torsion.

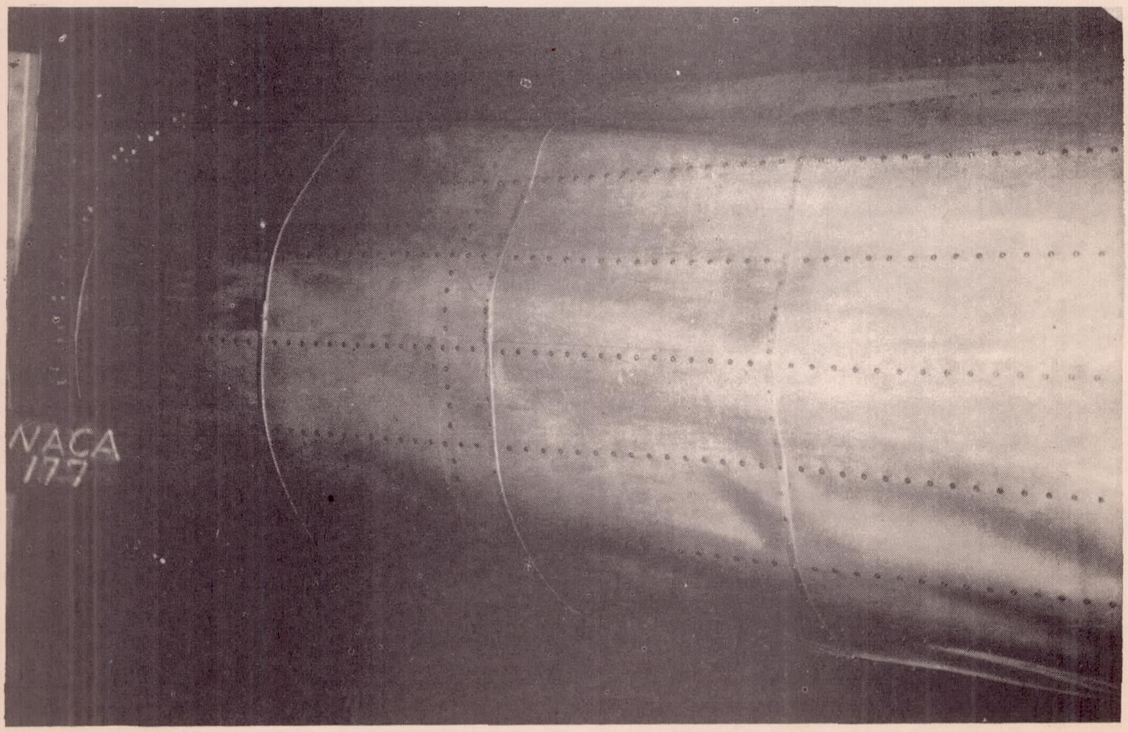


Figure 43.- Pure torsion.